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Araştırma Makalesi/Research Article

Nevşehir taşı tozunun kendiliğinden yerleşen harçlarda portland çimentosu ikamesi olarak değerlendirilmesi: erken yaşta mukavemet ve reoloji

Evaluation of Nevşehir stone powder as a portland cement substitute in self-compacting mortars: early-age strength and rheology

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ÖZ

Portland çimentosunun üretimi atmosferdeki karbondioksit emisyonlarının artmasına neden olmaktadır. Bu nedenle, Portland çimentosu yerine puzolanik özelliklere sahip doğal kaynakların ve atıkların kullanılması zorunlu hale gelmiştir. Bu makalede, kendiliğinden yerleşen harç yapımında Portland çimentosunun yerine kullanılabilecek doğal olarak oluşan puzolanik bir malzeme olan Nevşehir taşı tozunun etkinliği incelenmiştir. Portland çimentosu yerine %5, %10, %15 ve %20 oranlarında Nevşehir taşı tozu ilave edilerek hazırlanan harcın performansının değerlendirilmesi amacıyla bir laboratuvar çalışması yapılmıştır. Karışımların başlangıçtaki mekanik performansını incelemek için 40x40x160 mm boyutlarındaki prizmatik numuneler kullanılmıştır. Harçların yayılma çapları Avrupa İnşaat Kimyasalları ve Beton Sistemleri İhtisas Federasyonu standardı referans alınarak belirlenmiştir. Seçilen oranlarda Nevşehir taşı tozu ile oluşturulan numuneler, 23±2℃ sıcaklıktaki suya 3 gün süreyle daldırılmıştır. Kür süresi dolan numunelere erken yaş eğilme ve basınç dayanımı testleri uygulanmıştır. Deneysel analiz, en yüksek basınç dayanımlarının referans numunelerde ve Nevşehir taşı tozu ile %5 oranında çimento ikamesi içeren kombinasyonlarda görüldüğünü ortaya koymuştur. Ancak Nevşehir taş tozu miktarındaki artışla erken basınç dayanımında azalma olmuştur. Bu azalmalar sırasıyla NP5, NP10, NP15 ve NP20 serilerinde yaklaşık %1,3, %5,6, %15,7 ve %25,7'dir.

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ABSTRACT

The manufacturing of Portland cement is contributing to a rise in atmospheric carbon dioxide emissions. Consequently, the utilization of natural resources and waste materials possessing pozzolanic qualities in lieu of Portland cement has become imperative. This article examines the efficacy of Nevşehir stone dust, a naturally occurring pozzolanic material, as a substitute for Portland cement in the manufacturing of self-compacting mortar. A laboratory study was performed to assess the efficacy of mortar formulated with 5%, 10%, 15%, and 20% Nevşehir stone powder as a substitute for Portland cement. Prismatic specimens of 40x40x160 mm were utilized to assess the initial mechanical properties of the mixtures. The spread widths of mortars have been established according to the standards set by the European Federation of Specialist Construction Chemicals and Concrete Systems. Samples formulated with specified ratios of Nevşehir stone powder were submerged in water at a temperature of 23±2℃ for a duration of 3 days. Early age flexural and compressive strength tests were applied to the samples whose curing period had expired. The experimental analysis revealed that the highest compressive strengths were seen in the reference samples and in the combinations with a 5% substitution of cement with Nevşehir stone dust. However, with the increase in the amount of Nevşehir stone dust, there was a decrease in compressive strength. These decreases are approximately 1.3%, 5.6%, 15.7% and 25.7% in the NP5, NP10, NP15 and NP20 series, respectively.

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1. Introduction

Concrete, composed primarily of cement, is unarguably one of the most widely used construction materials [1], [2]. Cement is the predominant binding agent in both reinforced and unreinforced concrete. The global production of ordinary Portland cement (PC) increases about 9% annually [3]. The increasing rate poses a significant environmental danger due to the substantial carbon dioxide emissions generated during cement production [4]. The cement manufacturing sector is predicted to generate approximately 1.5 billion tons of greenhouse gasses yearly, or roughly 6% of global greenhouse gas emissions [5], [6]. Consequently, researchers have advocated for the development of methods to utilize other materials, agricultural and industrial wastes, or by-products in place of PC, due to the depletion of natural resources and the pressing necessity for their conservation [7], [8], [9], [10], [11], [12], [13]. Numerous studies have been undertaken about the application of pumice and volcanic ash (VA) in concrete and cement manufacturing [14], [15], [16]. Alqarni conducted a comprehensive literature analysis on the concrete qualities, including workability, compressive strength, flexural strength, split tensile strength, and durability performance of volcanic pumice powder ash (VPPA). The findings revealed that the use of VPPA with partial substitution diminishes workability and compressive strength, but enhancements in flexural and split tensile strength, as well as durability characteristics, are reported [17]. The study by Al-Zboon and Al-Zou'b analyzes the impact of Jordanian volcanic tuff aggregates on the characteristics of cement mortar. Tests for compressive strength, flexural strength, and unit weight were conducted at 3, 7, 28, and 56 days on five mortar mixtures utilizing volcanic tuff aggregate in place of conventional aggregate at proportions of 0, 25, 50, 75, and 100%. The results indicated that the compressive and flexural strength were highest for M3. The unit weight diminished with an increase in the volcanic tuff ratio [18]. The study by Arı attempted to ascertain the impact of stone dust grain size in composite mortar mixtures, utilized for the restoration of historical buildings constructed with Nevşehir stones, on strength. The study concluded that the composite mortar formulated with particles sized between 150-250 μm significantly enhanced the strength and surface contact angle of Nevşehir stone [19]. This research aims to investigate the changes in workability and viscosity properties resulting from the incorporation of natural pozzolans into self-compacting mortars (SCMs). For this purpose, a natural pozzolan, volcanic minerals such as Nevşehir stone dust (NP), which is abundantly found in Cappadocia region of Turkey, was used in the experimental study by substituting from 5% to 20% with cement due to its binding properties. As a result of the study, the effects of varying the ratios of NP instead of Portland cement in SCM formulation on early age flexural and compressive strengths of mortar, viscosity, workability and water consumption were investigated.

2. Materials and methods

2.1. Used materials

For this experimental work, type CEM I 42.5 ordinary PC conforming to TS EN 197-1 [20] standards were utilized. NP was utilized in conjunction with cement as a binding agent in the fabrication of SCM. Also, NP, composed of volcanic lava, is a type of volcanic tuff endemic to Cappadocia and its vicinity. The chemical components and physical characteristics of these powders are presented in Table 1. When Table 1 is examined, it can be said that Nevşehir stone has a strong pozzolanic potential. Because SiO_2 combines with calcium hydroxide to form calcium silicate hydrate (C-S-H), which increases the strength of the concrete. In addition, Al_2O_3 forms calcium aluminate hydrates, especially in the presence of water. This contributes to the increase in the strength of the mortar. The local natural river sand was used as fine aggregate with a nominal maximum size of 4 mm, specific gravity of 2.63, and water absorption of 1.91%. The aggregate gradation, illustrated in Figure 1. A liquid superplasticizer (SP) based on polycarboxylate, namely Sika Viscocrete SF 18, was utilized, possessing a specific gravity of 1.07. Figure 2 illustrates the aggregate and binder materials utilized for study.

Table 1. Chemical and physical properties of PC and NP.

Items (%)	PC	NP
SiO_2	18.90	71.42
Al_2O_3	4.36	18.07
Fe_2O_3	3.25	2.79
CaO	63.36	1.98
MgO	2.19	0.44
SO_3	3.29	0.03
Na_2O	0.40	0.1
K_2O	0.66	4.55
LOI	3.5	20.31
Specific gravity	3.1	2.61

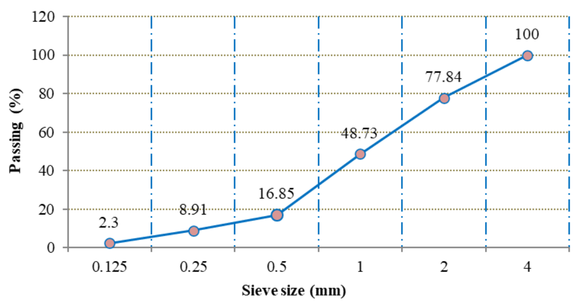

Figure 1. Particle size distribution of river sand.

Figure 2. Dry ingredients a) NP, b) PC, c) sand.

2.2. Mixes proportions

A reference mixture and four mixtures have been designed to assess the fresh and hardened characteristics of SCMs generated by replacing NP with varying quantities of PC. Table 2 shows the SCM ingredient compositions. The weight-based substitution rates were set at 0%, 5%, 10%, 15%, and 20%. The substitution of NP with cement as the pozzolanic material was made based on the substitution rates of different pozzolanic materials found in the literature [9], [21], [22], [23], [24], [25], [26]. Following multiple trial mixtures, the water/binder (W/B) ratios were determined to be 0.42, 0.42, 0.41, 0.41, and 0.41 for control, NP5, NP10, NP15, and NP20, respectively. For reference mixes, NP5, NP10, NP15, and NP20, the binder amounts in the produced mixtures were 600, 570, 540, 510, and 480 kg/m^3, respectively. The SP quantity was maintained constant and was chosen at 8 kg/m^3. All mix designs, as illustrated in Table 2.

Table 2. Design specifications of the mixes (kg/m^3)

ID	PC	NP	Sand	SP	W/B
Control	600	0	1417.51	8	0.42
NP5	570	30	1412.73	8	0.42
NP10	540	60	1421.11	8	0.41
NP15	510	90	1416.32	8	0.41
NP20	480	120	1411.54	8	0.41

2.3. Testing methods

The filling ability characteristics of SCMs were assessed by measuring slump flow diameter in accordance with the rules and requirements established by the European Federation of National Associations Representing Concrete (EFNARC) [27]. The filling capacity of mortar is defined as its ability to conform to the shape of the mold in which it is cast, solely under its own weight, especially in regions where barriers may impede its flow [28]. As shown in Figure 3, viscosity tests and the mini-slump flow test were used to assess the workability and fluidity characteristics of fresh mortars. The viscometer test is a technique employed to assess the fluidity of mortar. Assessing the workability and plastic characteristics of concrete/mortar is essential [29]. The combined mortar was put into a beaker for measurement using the Brookfield DVE viscosity device. It was measured how the mortar in the container changed its torsional moment when the shaft at the end of the gadget turned. The rheological qualities were assessed by measuring the rotational speed of the shaft between 1.0-100 rpm (increasing shear rate-shear stress) and 100-1.0 rpm (decreasing shear rate-shear stress) [30].

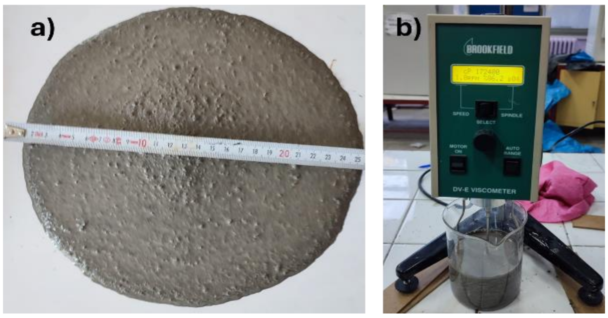

Figure 3. a) Dispersion diameter, b) viscometer test apparatus

Mechanical strength tests were performed on three 40x40x 160 mm prismatic specimens at 3 days of age. The samples were removed from the molds after 24 hours and subsequently cured in lime-saturated water at a temperature of 23 °C. As required by ASTM C348 [31] the mortars were put through a 3-day flexural strength test (Figure 4). Using the ASTM C349 [32] standard, the compression strength of each piece split in half under a loading speed of 2.4 kN/s was found after the flexural test.

Figure 4. Flexural strength test

3. Results

3.1. Fresh mortar properties

Slump flow was used to test the features of fresh SCMs that contained NP and PC. The Figure 5 illustrates the water consumption of the combinations necessary to attain a slump flow diameter of 240 ± 20 mm. The spreading diameter of the combination with 10% NP is identical to that of the control sample, whereas the slump values and water requirements of the mixtures with 15% NP and 20% NP are same.

The primary characteristic of SCMs is enough fluidity and resistance to segregation [33]. For these properties to be achieved in SCMs, sufficient viscosity, low shear stress, and cohesion are essential. The viscosity test of mortars including NP was conducted to assess their consistency and workability characteristics (Figure 6). This diagram shows that the viscosity of the samples decreases asymptotically as the angular speed of the spindle increases [9]. At the first two rotational speeds, the viscosity of the NP5 samples was lower than that of the control mixtures but superior to the other three mixtures. With the increase in rotational speed, the viscosity decreased in all samples, while high nanoparticle (NP) concentrations resulted in lower viscosity values compared to the control mixtures. The NP20 mixture showed the minimum viscosity at 100 RPM, while the control mixture showed the maximum viscosity at the lowest RPM. This indicates that the high NP content reduces the viscosity especially at increasing shear rates, and the improved flow behavior and shear thinning properties for the NP-substituted mixtures.

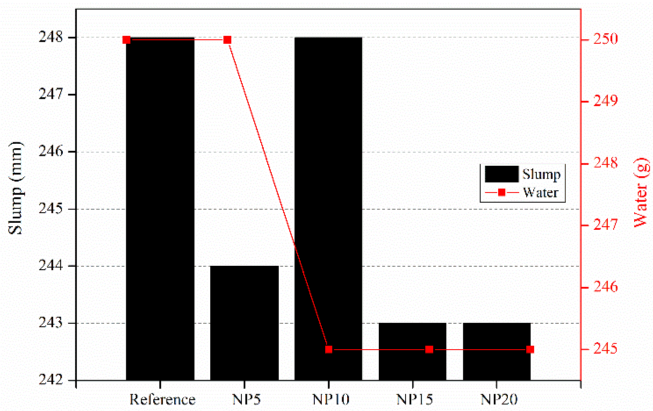

Figure 5. Slump flow diameter and water demands.

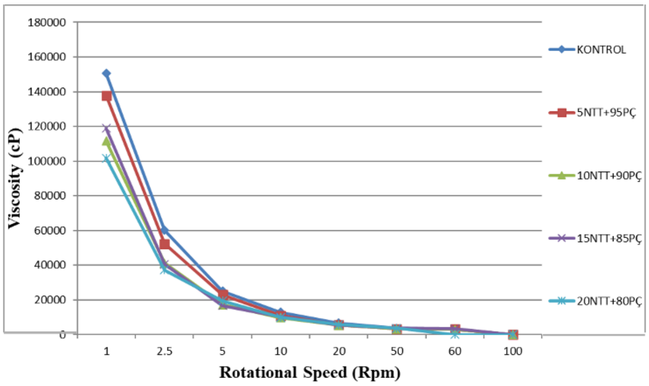

Figure 6. Viscosity test results.

3.2. Flexural and compressive strength

Figure 7 shows how NP changed the flexural strength of samples that were made into prisms over the course of three days. The incorporation of 5% NP enhanced the flexural strength relative to the reference samples. The incorporation of 5%, 10%, 15%, and 20% NP enhanced the early-age flexural strength relative to the reference samples. Comparing the 3-day flexural strengths of the control sample with those containing 5% NP, 10% NP, 15% NP, and 20% NP revealed increases of around 7%, 3.6%, 3.9%, and 6.4%, respectively. The 3-day flexural strength of the series containing NP surpassed that of the control sample, correlating with the increased NP ratio. Increasing the flexural strength of the mortar will provide advantages in creating longer-lasting elements, shortening the manufacturing process and against environmental conditions (e.g. freeze-thaw and humidity effects).

The compressive strengths of SCMs at 3 days are illustrated in Figure 8. The figure indicates that, relative to the reference mixtures, the 3-day compressive strength diminishes when the NP ratio escalates. These decreases are approximately 1.3%, 5.6%, 15.7% and 25.7% in the NP5, NP10, NP15 and NP20 series, respectively. Volcanic tuff contains minerals such as silica and aluminum oxide. These minerals cause changes in the microstructure by participating in the hydration reactions of the cement. Thus, they form components that provide lower early strength. This condition parallels the findings of the researchers [18].

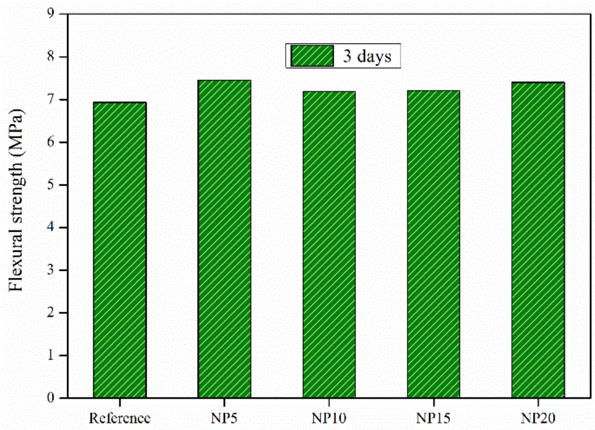

Figure 7. Flexural strength test results

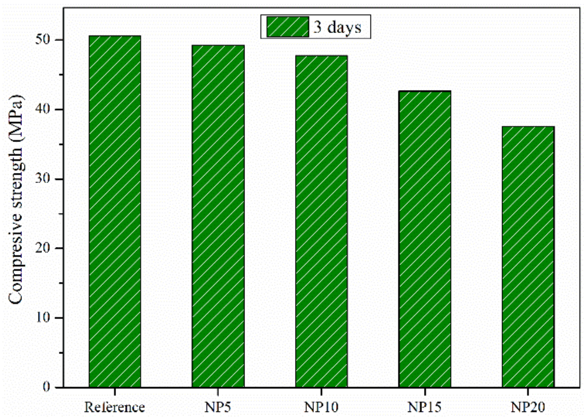

Figure 8. Compressive strength test results.

4. Conclusion

The experimental investigation examined the early age strength, workability and viscosity properties of self-compacting mortars (SCMs) including Nevşehir stone powder (NP) and Portland cement (PC). The results obtained are itemized below.

- The slump flow test results reveal that the combination with 10% NP demonstrated a spreading diameter akin to the control sample, whereas the mixtures with 15% and 20% NP exhibited comparable water demands and slump values. This indicates that the inclusion of NP up to 10% does not substantially affect fluidity relative to the control; however, elevating NP content to 15%

or greater necessitates increased water consumption to maintain equivalent workability**.**

- The results indicated that when the rotating speed rose, the viscosity measurements for all mixes diminished. At reduced rotation speeds, the NP5 mixture demonstrated lower viscosity compared to the control; nevertheless, as rotation speed escalated, the control blend displayed greater viscosity values than other NP-modified blends. The rising NP proportion resulted in a further reduction in viscosity, with the minimum viscosity recorded in the NP20 mix at elevated speeds, whereas the control blend exhibited the maximum viscosity at low rotating speeds.
- The data indicate that increased NP content in SCMs can decrease viscosity and enhance workability. However it may necessitate more water to achieve the appropriate slump flow rates. The diminished viscosity, especially at elevated NP concentrations, signifies improved fluidity, rendering NP an effective additive for enhancing the rheological characteristics of new mortars, while adequately preserving resistance to segregation.
- The experimental findings indicate that the integration of NP into SCMs enhances early-age flexural strength while adversely affecting compressive strength. The incorporation of 5% NP enhanced the flexural strength by roughly 7% relative to the control sample. These data indicate that NP positively influences early-age flexural performance, augmenting strength with increased NP ratios.
- Nevertheless, an analysis of the compressive strength at 3 days reveals a decline corresponding to a rise in NP content. The reduction in compressive strength with a larger fraction of NP aligns with prior research, suggesting that although NP improves flexural performance, it may diminish early compressive strength. Consequently, whereas NP demonstrates potential for enhancing flexural strength, its impact on compressive strength requires meticulous evaluation, especially in scenarios where early-age compressive strength is paramount.

5. Recommendations for future research

In future studies, the use of Nevşehir Stone powder in geopolymer mortars can be examined. In addition, in studies to be carried out as a substitute for cement, durability properties can be evaluated in more detail. Also, microstructure of samples can be assessed.

Ethics committee approval and conflict of interest statement

There is no need to obtain permission from the ethics committee for the article prepared

There is no conflict of interest with any person / institution in the article prepared

Authors' Contributions

Demir M: Experimental Study, data collection

Yön Şahin M: Analysis and interpretation of data, preparation of draft, Revision

Karataş M: Conceptual design and Revision

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