



Research Paper / Makale

**Effect of Porous Aggregate Size on the Techno-Mechanical Properties of
Cementless Lightweight Mortars**

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Abstract: The use of natural and porous materials is becoming increasingly common in construction applications. To reduce the dead load and to construct the high-energy efficient buildings, the products made from lightweight aggregates are often observed in civil engineering practices. One of the newest natural and porous aggregates is Alaçatı-Alapetra stone. This tuff-like rock type with the natural and porous characteristics is also nowadays gaining importance in construction materials sector. In addition to this, another important issue in the construction materials sector is the effort to create cement-free construction products due to environmental concerns. In this paper, the results of a comprehensive research work that is carried out on using of Alaçatı-Alapetra stone as a lightweight aggregate in cementless lightweight mortars were evaluated. Specially, the technical properties to be needed in developing a product with Alaçatı stone were presented in detail.

Keywords: Alaçatı stone; Alapetra stone; lightweight mortar; cementless mortar; mechanical behavior.

**Gözenekli Agreganın Boyutunun Çimentosuz Hafif Harçların Tekno-
Mekanik Özelliklerine Etkisi**

Özet: Doğal ve gözenekli malzemelerin inşaat uygulamalarında kullanımı gittikçe yaygınlaşmaktadır. Yapılarda ölü yükü azaltmak ve yüksek enerjili verimli binaları inşa etmek için, hafif agregalarla üretilen hafif yapıları ürünler sıklıkla inşaat mühendisliği uygulamalarında kullanılmaktadır. En yeni doğal, hafif ve gözenekli agregalardan bir tanesi de Alaçatı-Alapetra taşı olarak değerlendirilebilir. Doğal ve gözenekli özelliklere sahip bu tüf benzeri kaya türü günümüzde inşaat malzemeleri sektöründe önem kazanmaktadır. Buna ek olarak, inşaat malzemeleri sektöründe bir diğer önemli konu, çevreye karşı duyarlılık bağlamında, düşük oranda çimento bileşenli veya hiç çimento içermeyen inşaat ürünleri yaratma çabasıdır. Bu çalışmada, çimento içermeyen hafif harçlarda hafif agreganın boyutunun Alaçatı-Alapetra taşı kullanımını üzerinde yapılan kapsamlı bir araştırma çalışmasının sonuçları değerlendirilmiştir. Özellikle, Alaçatı taşı ile bir ürün geliştirmede ihtiyaç duyulan teknik özellikler ayrıntılı olarak sunulmuştur.

Anahtar kelimeler: Alaçatı taşı; Alapetra taşı; hafif harç; çimentosuz harç; mekanik davranış.

1. Introduction

Industrial rocks with volcanic natural origin and porous structure are increasingly used in the construction sector in various sizes. The porosity in the material also adds low unit volume weight to the material as well as the thermal insulation performance value. In order to reduce dead load and improve energy efficiency in buildings, low unit volume weight building materials are often seen to be applied. Lightweight composite mortars are known as mortars where lightweight aggregates are used and the desired weight reduction is achieved when compared to normal weight mortars.

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Lightweight aggregates used in the production of lightweight construction materials have a wide distribution range and differ from each other in terms of origin, appearance, density, class, surface condition, porosity, mechanical strength, water absorption and cost. Their widely used names vary according to their origins and country of production.

In Turkey, an alternative natural lightweight aggregate type that can be used in various sizes is located in İzmir-Alaçatı Region. This lightweight porous aggregate derivative is also known as "Alaçatı-Alapietra" stone. This new aggregate type, which is generally used as a wall covering stone, has been gained the experience that it can be used as aggregate in mortars and lightweight concretes in previous experimental researches [1].

On the other hand, researchers have been trying to remove or reduce cement from mortar/concrete in recent years in order to reduce the release of too much carbon dioxide from the cement production to the environment. In this context, the importance of cementless mortar/concrete production and application is increasing recently. In the production of cementless products, aggregates have a very important effect on product performance as well as the effect of binders. In addition, porous aggregates have an important influence on the mechanical behavior of the final product.

In Izmir Katip Çelebi University Department of Construction Materials R&D Innovation Laboratory, a series of experimental studies have been carried out on cementless mortar production. The effects of using Alaçatı-Alapietra stone in different sizes as lightweight porous aggregate on techno-mechanical properties of cementless mortars are investigated within the scope of this experimental study. The results of this study will be discussed in detail in this paper.

2. Materials and Methods

2.1. Alaçatı-Alapietra Stone

Alaçatı-Alapietra stone is produced in a decorative stone (marble) quarry in İzmir-Alaçatı Region. The stone is a volcanic, whitish colored and porous rock type with basalt granules in it. Because of its locally availability, the material known as "Alaçatı Stone" or "Alaepietra Stone" has been used for a long time in the region and widely used for stone house construction. The soft character of Alaçatı-Alapietra stone makes itself easy to chop and shape. The most interesting feature of this stone is its hardness when it comes in contact with air, wind and sun, even though it is soft when removed from the quarry [2]. The volcanic rocks in the area where the Alaçatı stone formation is located are tuff, tuffite, agglomerate, andesite and basalts. The tuffites, which present a distinct stratification, are volcano-sedimentary. The general characteristics of the Alaçatı-Alapietra stone located in the region are given in Table 1.

In macroscopic and microscopic examinations, 58% to 74% of the pumice aggregate particles were found in the sized Alaçatı stone aggregates. According to the findings, it was determined that the Alaçatı stone material could be named as "pumice-containing tuffite aggregate" or "pumice-containing volcanic tuff aggregate" in petrographic terms [1].

In this experimental research, Alaçatı-alapietra stone was supplied from the stone quarry. Due to the softness of the Alaçatı stone, large scale of waste/residue Alaçatı-Alapietra stone is produced in the quarry and factory operation. This waste and/or residue material accumulates more and more every day. However, industrial use of this material is not yet common. In the scope of this study, the evaluation of this valuable waste/residue material in cementless mortar was investigated.

Table 1. General characteristics of Alaçatı-Alapietra stone [2].

General Physical Characteristics	
Unit Volume Weight	1370 kg/m ³
Specific Gravity (DIN52102)	2.36 gr/cm ³
Total Porosity	%42.06
Compressive Strength	16.29 N/mm ²
Matrix (Fine Ash-Glass)	% 15-20
Riolite Lava - Glass Fragments	% 10
Basalt Lava	% 5-10
Pumice Fragments	% 60-70
Feldspar - Quartz	% 3-5
Amphibole - Pyroxene	% 1.5

2.2. Calcium Sulfate Anhydrite

Calcium sulfate (gypsum) is a widely used binder in the interior parts of buildings. The application are of gypsum is indoor of buildings because of its water solubility. It is commonly used because of its easy production phases, environmental friendliness, low production cost and visual aesthetics features [3-5].

Gypsum has been used in the production of plasters mainly in hemihydrate and anhydrite form for use in construction sector. Although there are many studies on hemihydrate in literature, studies on the use of anhydrite in mortar production are limited.

Anhydrite is a kind of gypsum that does not contain water in terms of its rock formation. In this study, natural anhydrite (NA) was evaluated as a binder material. Natural anhydrite as the most basic definition is anhydrous calcium sulfate (CaSO₄). It is a mineral containing of no water of crystallization. When the natural anhydrite mixed with water, it turns into a solid and stable material like the gypsum dihydrate (CaSO₄.2H₂O) again, without the need for any other binder.

2.3. Other Raw Materials

In this research, tuff aggregates supplied from Aksaray Region in Turkey was used in the production of control samples. Control samples were produced by using tuff aggregates instead of Alaçatı-Alapietra stone. Tuff aggregates have been reviewed many times in the literature and it is widely accepted that they are suitable for use lightweight mortars [6].

In this experimental work, expanded perlite and glass fiber supplied from the domestic market and they were used in the mixture combinations. Expanded perlite has been found to be used in the production of many materials in the literature and construction sector due to its lightweight and porous structure and insulating properties. It has also been used in this experimental study to take advantage of similar benefits of its. And the glass fibers in certain amount were used to improve the mechanical properties of the mortar specimens.

Anhydrite is a kind of gypsum that does not contain water in terms of its crystallization formation. It hardens very quickly when it reacts with water. So that the duration of the setting must be delayed to ensure the workability and commercial requirements of the anhydrite based lightweight mortars. In order to delay the setting time of the calcium sulfate anhydrate based mortar samples, a new generation setting retarder biopolymer (SRB), which was developed in the Izmir Katip Çelebi University Department of Construction Materials R&D Innovation Laboratory, was used in the mixture combinations. This SBR was developed based on some fatty acids.

2.4. Methodology

In this experimental study, different mixing ratios were designed to investigate the effect of waste/residue Alaçatı-Alapietra stone on the cementless composite mortars. In addition, in order to be able to analyze the effects that may arise from the use of Alaçatı-Alapietra stone, a separate mix without Alaçatı-Alapietra stone was also designed as the control mixture. The design of the mortar combinations is given in Table 2. Mixing ratios were carried out according to the design methodology specified in TS EN 13279-1 and the relevant standards.

Tablo 2. Mixing design of the cementless mortar.

Mixtures	NA (wt%)	1–2 mm Alaçatı stone (wt%)	0–1 mm Alaçatı stone (wt%)	Glass fiber (wt%)	Expanded perlite (wt%)	SRB (wt%)	0-2 mm Tuff (wt%)
AL50-C	50,0	-	-	1	1	0,5	47,5
AL50-1	50,0	9,5	38,0	1	1	0,5	-
AL50-2	50,0	19,0	28,5	1	1	0,5	-
AL50-3	50,0	28,5	19,0	1	1	0,5	-
AL50-4	50,0	38,0	9,5	1	1	0,5	-
AL40-C	40,0	-	-	1	1	0,5	57,3
AL40-1	40,0	11,5	46,0	1	1	0,5	-
AL40-2	40,0	23,0	34,5	1	1	0,5	-
AL40-3	40,0	34,5	23,0	1	1	0,5	-
AL40-4	40,0	46,0	11,5	1	1	0,5	-

In order to investigate the effect of Alaçatı-Alapietra aggregates on the development of lightweight mortar characteristics, two major aggregate sizes were evaluated for the aggregate. Alaçatı-Alapietra aggregates prepared in 0-1 mm dimension are called "fine aggregate" and Alaçatı-Alapietra aggregates prepared in 1-2 mm dimension are called "coarse aggregate" for this experimental study. In order to investigate the effect of Alaçatı-Alapietra aggregate, a series of mortar samples without Alaçatı-Alapietra aggregate as an initial study were prepared with 0-2 mm sized tuff aggregates, which were used in the control mixtures. Two different binder ratios (50% and 40%) were used in the mix design. In the sample coding systematic, the initial AL letters symbolize the Alaçatı-Alapietra stone. Followed by the numbers 50 and 40 representing the binder percentage by weight. The part separated by a hyphen indicates control samples (C) and other mixtures (1, 2, 3, 4).

In order to determine the optimum water/solid ratio in the preparation of mortar samples, consistency analysis was carried out by flow table apparatus. To determine initial and final setting time of mortar samples, vicat apparatus were used. Compressive strength test and flexural strength test was carried out on 40mm x 40mm x 160mm prismatic samples.

3. Research Findings

3.1. Consistency

It is necessary to determine at what amount the mixing water is needed to form fresh mortar. For this reason, the consistency analysis measurement is determined using the flow table method according to the ASTM C230 standard. With this method, the appropriate water content of the mixtures prepared as fresh mortar were obtained on the basis of the average spread diameter of 165 ± 5 mm [7]. In Table 3, according to mixing water amounts, water/solid ratios (W/S) are given. In 40% binder containing mortar samples, the aggregates absorbed more water while forming fresh mortar, because the aggregate ratio is higher in this mixture series. So that the water/solid ratio of

these mixtures was determined to be higher than the water/solid ratio of 50% binder containing mortar samples. Also, a sample photo from flow table test is given in Figure 1.

Table 3. Analysis findings of the mortar samples.

Mixtures	W/S ratio	Fine/coarse aggregate ratio	Hardened density (kg/m ³)	Consistency (mm)	Initial setting time (min)	Final setting time (min)	Compressive strength (MPa)
AL50-C	0.42	1.00	1242	165±5	30	41	4.188
AL50-1	0.42	4.00	1217	165±5	30	42	7.144
AL50-2	0.43	1.50	1189	165±5	36	46	6.169
AL50-3	0.41	0.67	1156	165±5	33	44	5.651
AL50-4	0.42	0.25	1135	165±5	32	44	5.104
AL40-C	0.43	1.00	1212	165±5	38	50	3.496
AL40-1	0.47	4.00	1177	165±5	42	49	6.035
AL40-2	0.44	1.50	1140	165±5	41	49	5.551
AL40-3	0.45	0.67	1081	165±5	42	50	4.962
AL40-4	0.45	0.25	1023	165±5	42	52	4.364



Figure 1. The views from flow table, setting time and hardened mortar samples.

3.2. Setting Time

The measurement of the setting time of fresh mortars was performed using vicat apparatus according to the principles in ASTM C 191 standard. The initial setting time should not be less than 20 minutes in order to maintain the proper workability period in calcium sulfate bonded mortars [8]. Table 3 shows the initial and final setting times of the mortar samples. According to the test results, as the calcium sulfate anhydrite ratio in the mixtures decreases, the setting time of samples extends. The initial setting times of the mixtures containing 50% calcium sulfate anhydrite were determined to be 30 minutes and final setting times were determined to be 40 minutes on average. In 40% anhydrite binding samples, the settling time increased although the setting retarder agent was reduced. In this series, the initial setting time of the samples were found as 40 minutes and the final setting times were 50 minutes on average. The settling times have been found to provide the requisite workability in the design of both two different binder proportions (initial setting > 20 min.). Also, an example from setting time analysis is given in Figure 1.

3.3. Flexural Strength

In this experimental study, tests on compressive strength and flexural strength were carried out on prismatic specimens in order to evaluate the mechanical properties of the mortars. Compressive and flexural strength tests were conducted to relevant EN standards on 40x40x160 mm prismatic test samples; compressive and flexural strength were determined as the average value taken from 3 specimens as per the relevant standards. The samples removed from the molds were left in the

casting room for 7 days in accordance with the experimental conditions and then dried in the oven at $40\pm 2^\circ\text{C}$ until constant weight was reached. After the drying process is completed, the samples are cooled again until the sample temperature reaches room temperature. Flexural strength and fine/coarse aggregate ratio relationship is given in Figure 2 and 3. In this study, samples produced with 50% binding ratio are included in B1 class (high gypsum ratio) and samples produced with 40% binding are included in B2 class (low gypsum ratio), according to the TS EN 13279-1 standard. It is stated in the standard that the flexural strength values of those class mortar specimens should be at least 1 MPa.

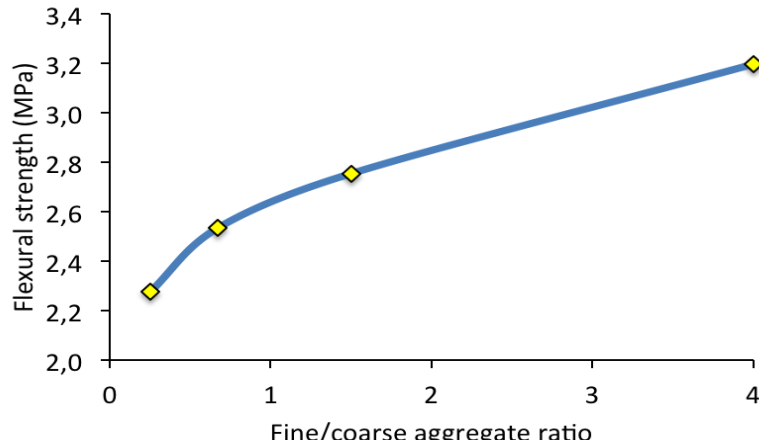


Figure 2. Relationship between flexural strength and fine/coarse Alaçatı-Alapietra aggregate ratio for %50 binder containing samples.

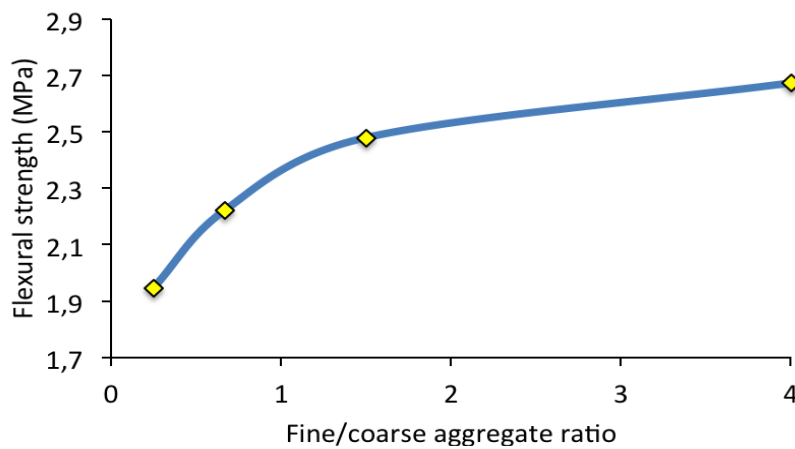


Figure 3. Relationship between flexural strength and fine/coarse Alaçatı-Alapietra aggregate ratio for %40 binder containing samples.

The flexural strength of the calcium sulfate anhydride mortar mixes is shown in Figs. 2 and 3. An inspection of Figs. 2 and 3 indicates that an exponential relationship exists between the flexural strength and the fine/coarse Alaçatı-Alapietra aggregate ratio. The test results showed that flexural strengths of all batches increase depending on the increase in the fine/coarse Alaçatı-Alapietra aggregate ratio. Maximum flexural strength value was recorded as a value of 3,20 MPa with batch of %50 calcium sulfate binding and fine/coarse aggregate ratio value of 4. The flexural strengths of all mixtures were found to be higher than the flexural strengths of control samples produced using tuff aggregates.

3.4. Compressive Strength

Gypsum mortar and gypsum plaster must have a compressive strength value at acceptable levels for use in different areas of the construction industry. This value, also referred to as the material strength, can vary depending on the material used and the location of use. In TS EN 13279-1 standard, mortars with a gypsum binder ratio of at least 50% are classified as B1 class and those with a gypsum binder ratio of less than 50% are classified as B2 class. In this study, samples produced with 50% binding ratio are included in B1 class (high gypsum ratio) and samples produced with 40% binding are included in B2 class (low gypsum ratio), according to the TS EN 13279-1 standard. It is stated in the standard that the compressive strength values of those class mortar specimens should be at least 2 MPa for both classes.

In this study, 7 days compressive strength values of Alaçatı-Alapietra stone aggregate calcium sulfate anhydrite mortar samples according to the standard were analyzed and the findings are given in Table 3.

The compressive strength is determined by applying one of the breaking pieces broken from the test sample used in the tensile strength test. The compressive strength values of the mortar specimens are given graphically in Figure 4 and 5 depending on the change in fine/coarse Alaçatı-Alapietra aggregate ratio.

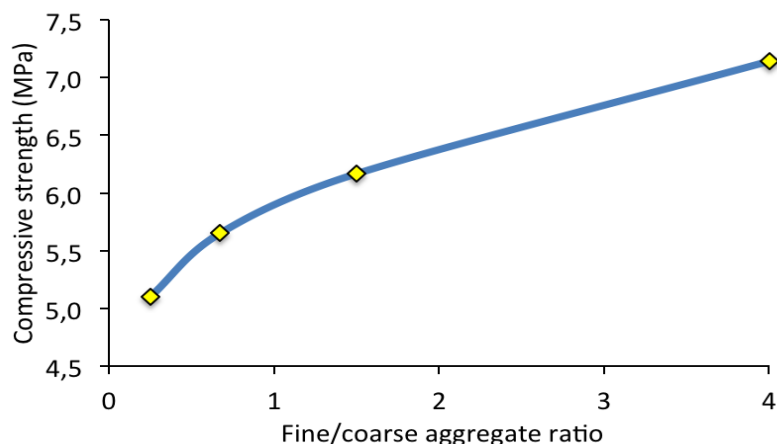


Figure 4. Relationship between compressive strength and fine/coarse Alaçatı-Alapietra aggregate ratio for %50 binder containing samples.

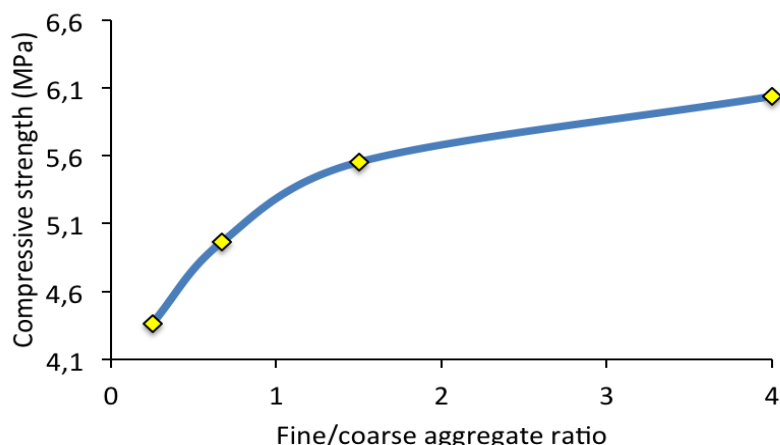


Figure 5. Relationship between compressive strength and fine/coarse Alaçatı-Alapietra aggregate ratio for %40 binder containing samples.

The compressive strength of the calcium sulfate anhydrate mortar mixes is shown in Figure 4 and 5. Relation of the fine and coarse aggregate ratio plays an important role in the compressive strength values of the mortar specimens. It is observed from the test results that in general, as Alaçatı-Alapietra coarse aggregate ratio increases, in other words aggregate porosity increases, compressive strength of mortar samples decreases. When considered in terms of the limit values stipulated in TS EN 13279-1 standard, it was determined that all compressive strength values were provided necessary compressive strength value (>2 MPa). The increase in the ratio of Alaçatı-Alapietra fine aggregate in the mixtures was found to be a factor increasing the strength value of the mortar. As shown in table 3, the compressive strength value of the control sample with 50% binding ratio was determined to be 4.19 MPa. It was observed that the compressive strength values of the 50% binder containing and using Alaçatı-Alapietra aggregate were significantly higher than those of the control sample. A similar phenomenon was also obtained for samples produced using 40% binder. The highest compressive strength is the samples produced with fine/coarse aggregate ratio of 4 and 50% binder (7.14 MPa).

4. Conclusions

In this study, the use of Alaçatı-Alapietra stone, found as waste / residue from production, on calcium sulfate anhydrite binding mortars has been examined experimentally. According to the test results, it is observed that the workability time can be adjusted by preventing the early hardening of the mortar with setting retarder additives at certain ratios. It has been observed that the Alaçatı-Alapietra aggregated mortars can attain the desired consistency with an average water/solid ratio of 0.42. In addition, when compared with the control samples produced with tuff aggregates, the mechanical strengths of the mortars produced with Alaçatı-Alapietra aggregates were found to be higher. Although the control samples produced with tuff aggregates have lower unit weight values, the values of compressive strength and flexural strength of the samples produced with Alaçatı-Alapietra aggregates are quite high. In this study, it is concluded that the use of Alaçatı-Alapietra stone as an aggregate in cementless mortars is suitable.

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