A Research on Developing Zeolite Based Lime Mortars

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Abstract. Zeolites are aluminosilicate materials that possess a crystalline structure characterized by an interlinked three-dimensional framework of AlO_4 and SiO_4 tetrahedra. This framework contains open cavities in the form of channels and cages, leading to the designation of zeolites as molecular sieves. The characteristics of molecular sieves enable zeolites to have high adsorption capacity, ion exchange capability, and catalytic properties, which also contribute to improving indoor environmental quality. Zeolites also exhibit pozzolanic reactivity due to their high silica content. These chemical and physical properties of zeolites offer the potential to produce a lime-based mortar with improved mechanical performance, which can also contribute to the physical conditions of the environment with its hygroscopic behavior. For this purpose, under the scope of the research, the pozzolanic reactivity of zeolite obtained from the Manisa Gördes region of Türkiye has been evaluated first. After establishing the pozzolanic property of zeolite, mortar alternatives with different pozzolan/binder ratios, curing conditions, and aggregate sizes are investigated through a combination of physical and mechanical testing methods. Clinoptilolite-type natural zeolite in the form of powder and aggregates, which vary between 0-7 mm (0-2 mm, 2-4 mm, 4-7 mm) particle size, and class CL 90 – S type slaked lime were used to produce zeolite based lime mortars. The different particle sizes of zeolite aggregates were added to increase the moisture adsorption capacity of the mortar.

1 Introduction

In recent decades, shifts in lifestyle have resulted in people spending 70–90% of their time indoors, frequently encountering unhealthy environments [1]. Increasing the airtightness of buildings to meet energy-efficiency targets has led to a decrease in indoor environmental quality (IEQ) due to poor ventilation [2]. Another wake-up call regarding the importance of IEQ came in the aftermath of the COVID-19 pandemic. Substandard quality may result in various health issues, including respiratory problems, headaches, and allergies [3]. IEQ is crucial as it impacts not only our physical health but also our mental well-being and

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productivity. These facts highlight the importance of researching finishing materials, such as mortars that passively enhance IEQ and have lower embodied energy, as alternatives to cement mortars.

Using porous and/or adsorbent materials to regulate humidity levels in indoor environments without increasing the energy costs of the building due to their hygroscopic behavior is a recent growing interest. There are studies on the moisture buffering behavior of mortars with different porous adsorbent aggregates, such as zeolite, perlite, silica, active carbon, etc., with high hygroscopic buffering capacity [2].

Zeolites are aluminosilicate minerals that possess a crystalline structure characterized by an interlinked three-dimensional framework of AlO_4 and SiO_4 tetrahedra [4]. This framework contains open cavities in the form of channels and cages, leading to the designation of zeolites as molecular sieves. The characteristics of molecular sieves enable zeolites to have high adsorption capacity, ion exchange capability, and catalytic properties [5], which also contribute to improving IEQ. In addition to their contribution to humidity control, zeolites can also help prevent microbial growth on surfaces as an antibacterial agent [6].

Zeolites have various applications in construction, including:

- Use as a mineral admixture in concrete, helping inhibit alkali-aggregate reactions that can cause concrete to expand and crack [6].
- Creating lightweight cellular concrete, reducing the overall structural weight while maintaining strength [6].
- Producing natural zeolite-based carrier fluidizing agents (CFAs) to significantly improve concrete workability, facilitating ease of pouring and shaping [6].
- Serving as internal curing agents due to their water adsorption and desorption characteristics [7].
- Blending with other materials in cement manufacturing to enhance the properties of cement [6].
- Replacing Portland cement, mainly due to their pozzolanic activities [8].

Furthermore, alongside these various applications, there are also studies that investigate the use of zeolite as a pozzolanic material. As they are a family of hydrated aluminosilicates with high contents of reactive silica and alumina [9], natural zeolites are known for their pozzolanic properties [10]. Due to their excellent pozzolanic activity, their parent rocks (zeolitic tuffs) have frequently been used since Roman times as admixtures in cement for various types of construction. The reactivity of natural zeolites arises from (a) their highly porous structure and the related large external surface area, (b) metastability, and (c) ion exchange ability, all of three parameters favoring interaction with lime. Accordingly, zeolite crystals are easily dissolved in the alkaline contact solution, giving rise to the precipitation of hydrated calcium silicates and aluminates (C-S-H and C-A-S-H), which have cementitious properties [9].

Adding pozzolan to air lime improves the mortar's hydraulic properties, water resistance, compressive strength, durability, and resistance to weathering [11]. Today, lime-pozzolan mortars are mostly used in restoration interventions to ensure compatibility with authentic building materials [12]. They also have the potential to be utilized as ecological alternatives to cement-based mortars.

Together, these applications illustrate the transformative potential of using natural zeolite to address a range of construction-related issues. Additionally, as a relatively inexpensive and easily extracted and processed raw material, zeolite has the potential to lead to economically cost-effective and environmentally friendly building materials with superior properties, such as improving indoor environmental quality [13]. Notably, Türkiye ranks among the top in the world for the production and deposits of zeolites, following China, Korea, and the USA, making zeolite a local and abundant material resource [14].

In this framework, the purpose of the present study is to investigate the potential of producing a zeolite and lime-based mortar with improved mechanical performance, which can also contribute to IEQ by humidity conditioning. Under the scope of the research, firstly, the pozzolanic reactivity of the natural zeolite (NZ), obtained from the Manisa Gördes region of Türkiye, has been evaluated. After establishing the pozzolanic property, mortar alternatives with different pozzolan/binder ratios, curing conditions, and aggregate sizes are investigated through the combination of physical and mechanical testing methods. The varying pozzolan-to-binder ratios and curing conditions are being studied to understand the hydraulic behavior and enhance the overall performance of the mortars. Additionally, the inclusion of NZ aggregate with different sizes is being investigated to determine its potential for increasing adsorption and, consequently, moisture buffering behavior.

2 Materials and Methods

2.1 Materials

Natural zeolite–clinoptilolite (NZ) used in this study was obtained from Manisa - Gördes region, Türkiye. NZ utilized as pozzolan was ground to under 50 microns, and used in different proportions in the binder. Coarse NZ was used as aggregates in three different gradations instead of sand (Figure 1) within different mortar mixtures. The lime binder used in all mixtures was hydrated calcium lime powder, defined as CL 90-S according to TS EN 459-1 [15]. CEN Standard Sand, according to TS EN 196-1 [16], was used for reference mixtures. The chemical compositions of lime and NZ, supplied by the manufacturer are given in Table 1.

Sand **0-2 mm Zeolite** **2-4 mm Zeolite** **4-7 mm Zeolite**

Fig. 1. Sand and Zeolite aggregates used in the study.

Table 1. Chemical analysis of the main components of Lime and Zeolite.

Component	SiO_2	Al_2O_3	Fe_2O_3	MnO	TiO_2	MgO	BaO	SrO	P_2O_5	CaO	Na_2O	K_2O	SO_3	Cl
Lime (%)	0,497	0,218	0,203	-	-	1,538	-	0,048	0,068	96,709	0,077	0,108	0,504	0,029
Zeolite (%)	71,6	11,3	1,39	0,02	0,08	0,86	< 0,01	0,03	0,011	2,27	0,86	3,67	-	-

2.2 Mixtures: composition, mixing and curing conditions

Eight different mortar samples were prepared in which the zeolite/lime ratios in the binder, aggregate type (sand/zeolite), and aggregate sizes were changed. Four of these were produced in two sets to test different curing conditions. Samples were coded in ZXX-XX-X format. The first two letters indicate the zeolite ratio in the binder (67, 50, 33), the next two letters indicate the aggregate type (Zeolite: Z; Sand: S) and maximum grain size (2:TS EN 196-1 Granulometry, 4:2-4 mm,7:4-7mm) and the last letter represents the curing conditions (Heat curing: H; Steam Curing: ST). The proportions of the mortar mixtures by weight are presented in Table 2.

Table 2. Mortar mixtures proportions by weight.

Sample ID	Lime (g)	Zeolite (Pozzolan) (g)	Water (g)	Aggregates			
				Sand (g) (EN 196-1)	Zeolite		
					0-2 mm	2-4 mm	4-7 mm
Z67 S2 H	150	300	450	1350	-	-	-
Z50 S2 H	225	225	450	1350	-	-	-
Z33 S2 H	300	150	460	1350	-	-	-
Z67 Z2 H	150	300	796	-	1350	-	-
Z50 Z2 H	225	225	796	-	1350	-	-
Z33 Z2 H	300	150	796	-	1350	-	-
Z50 Z4 H	225	225	870	-	-	1350	-
Z50 Z7 H	225	225	865		-	-	1350
Z50 S2 ST	225	225	450	1350	-	-	-
Z50 Z2 ST	225	225	777	-	1350	-	-
Z50 Z4 ST	225	225	858	-	-	1350	-
Z50 Z7 ST	225	225	865	-	-	-	1350

Z: Zeolite, S: Sand, H: Heat Curing, ST: Steam Curing
Specific gravities (g/cm^3): Sand: 2.56; Zeolite: 2,02; Hydrated Lime: 2,21

The pozzolanic activity of NZ was investigated according to Turkish Standard 25 [17]. For this purpose, mortar specimens were prepared by mixing hydrated lime, standard sand, and zeolite, which were then subjected to mechanical testing after the specified curing procedure. As a result of this test, NZ met the mechanical performance criteria of TS 25 as a pozzolan.

The NZ content was applied as a partial replacement of lime in amounts of 67%, 50%, and 33% by weight to assess the influence of the pozzolan/lime ratio. To investigate the effect of NZ as aggregate, sand was replaced by NZ with the same particle size distribution. The mortar mixture with NZ aggregate (0-2 mm), which gave the highest strength results, was also investigated with two gap-graded aggregates with particle sizes between 2-4 mm and 4-7 mm, respectively, to study the effect of varying aggregate sizes on the mortar properties. All mixtures were prepared and molded according to the mixing procedure in TS EN 196-1. For the NZ aggregate, pre-wetting was applied as is usual for lightweight aggregates. The total water contents of the mixtures were determined according to the flow table test standard EN 1015-3 [18], and the flow of the mixtures was fixed at 140 ± 5 mm.

The mixtures prepared for mechanical experiments were shaped in 40x40x160 mm standard mortar molds, and each property presented is the average of three samples (Figure

2). For adsorption-desorption experiments, they were shaped in 10x50x50 mm molds, and four samples of each type were used.

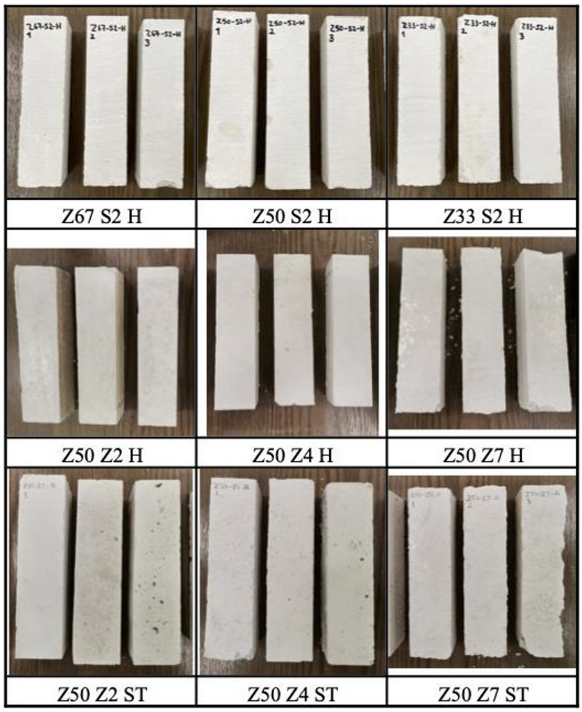

Fig. 2. Prepared zeolite-lime mortar samples.

Pozzolanic lime mortars are known to need long periods for strength gain, and often special curing conditions are applied to shorten these periods [19]. Elevated temperature and humid conditions are associated with higher pozzolanic reaction rates, thus improving the strength gain of pozzolanic mortars.

Two curing regimes were set up within this study: heat curing (H) and steam curing (ST), which were proven successful in early strength development in a prior study with another natural pozzolan, Earth of Datça [20]. These regimes were chosen to achieve acceptable strength in a shorter time with low energy consumption, which is beneficial for the production of prefabricated building elements as well.

The samples were covered with a polyethylene cover and pre-cured for 36 hours at 95±5% relative humidity (RH) and room temperature. For heat cure, the samples were removed from the molds, covered with a polyethylene cover, and cured in an oven at 55°C for 6 days at 95±5% RH. At the end of the 6th day, the samples were taken out of the oven and kept in a desiccator until they reached ambient temperature before the physical and mechanical tests. For steam curing, the samples were demolded and cured at 70 °C under saturated steam with low pressure (7500 Pa) in a closed container named Kerman for 6 hours. The temperature rise of the container was set at 35 °C per hour, and the curing cycle at 70 °C was maintained to ensure a gradual warming up and cooling down.

2.3 Testing methods

After the preparation and curing process, the unit weights of the samples were measured according to TS EN 1015-10[18], and water absorption capacity under atmospheric pressure was assessed according to TS EN 13755[21]. The samples prepared for mechanical tests were subjected to ultrasonic pulse velocity measurement using a Tico Prosec brand device, according to TS EN 14579 [22]. Flexural and compressive strengths were measured with a universal testing machine, 'MFL,' with a capacity of 100 kN, according to TS EN 196-1.

The adsorption-desorption behaviors of zeolite-lime mortar samples were investigated through weight change using a precision balance with 3-digit accuracy after being subjected to specified environmental conditions inside an Espec PRP-K2 brand environmental chamber. The environmental chamber was initially set to a constant cycle, simulating optimal indoor thermal comfort conditions at 24.4°C and 60% RH (for both summer and winter situations) [23-24]. The weight differences of the samples were monitored over 24-hour cycles to determine their moisture adsorption capacity for five days. After following five measurements, when the difference between two consecutive mass changes was 0.01%, it was assumed that the samples had reached their maximum adsorption capacities.

The measurements then continued to determine the behavior of the samples under variable fluctuating humidity and temperature conditions. For this cycle, two different thermal conditions were set up. The simulated environment alternated between 8-hour and 16-hour cycles, which is also referred to as a cycle period in the NORDTEST method [25], aligning with the occupancy hours of spaces such as offices and classrooms. The 16-hour period continued with the same conditions as the previous cycle: 24.4 °C and 60% RH, defined as a thermal comfort zone [23]. The 8-hour cycle was intentionally set at a maximum level considered *'extreme caution'* according to the heat index chart taken from the General Directorate of Meteorology of Türkiye [26] 30.1°C and 85% RH.

3 Results and Discussion

3.1 Physical and Mechanical Properties

3.1.1 Influence of Pozzolan / Lime ratio

NZ as a natural pozzolan, meets the TS 25 requirement of a minimum compressive strength of 4 MPa with a measured value of 7.89 MPa. In a previous study conducted with Datça natural pozzolan [20], the same value was found to be 8.10 MPa. Therefore, it is established that NZ provided a pozzolanic reaction with lime.

The compressive strength value of 8.19 MPa obtained for the pozzolan/lime ratio of 2/1 (Z67-S2), decreased to 6.89 MPa (0.84 times) for the 1/1 ratio (Z50-S2), and to 4.88 MPa (0.60 times) for the 1/2 ratio (Z33-S2).

As the proportion of pozzolan in the binder decreased, the compressive and flexural strengths deteriorated (Figure 3). This indicates that the Z67 mixture contained a sufficient amount of zeolite pozzolans for the lime to achieve a higher pozzolanic reaction rate in the binder. On the other hand, even Z33 mortar, which had the lowest compressive strength (4.88 MPa), can still be classified as moderately hydraulic lime mortar and used in buildings according to its compressive strength.

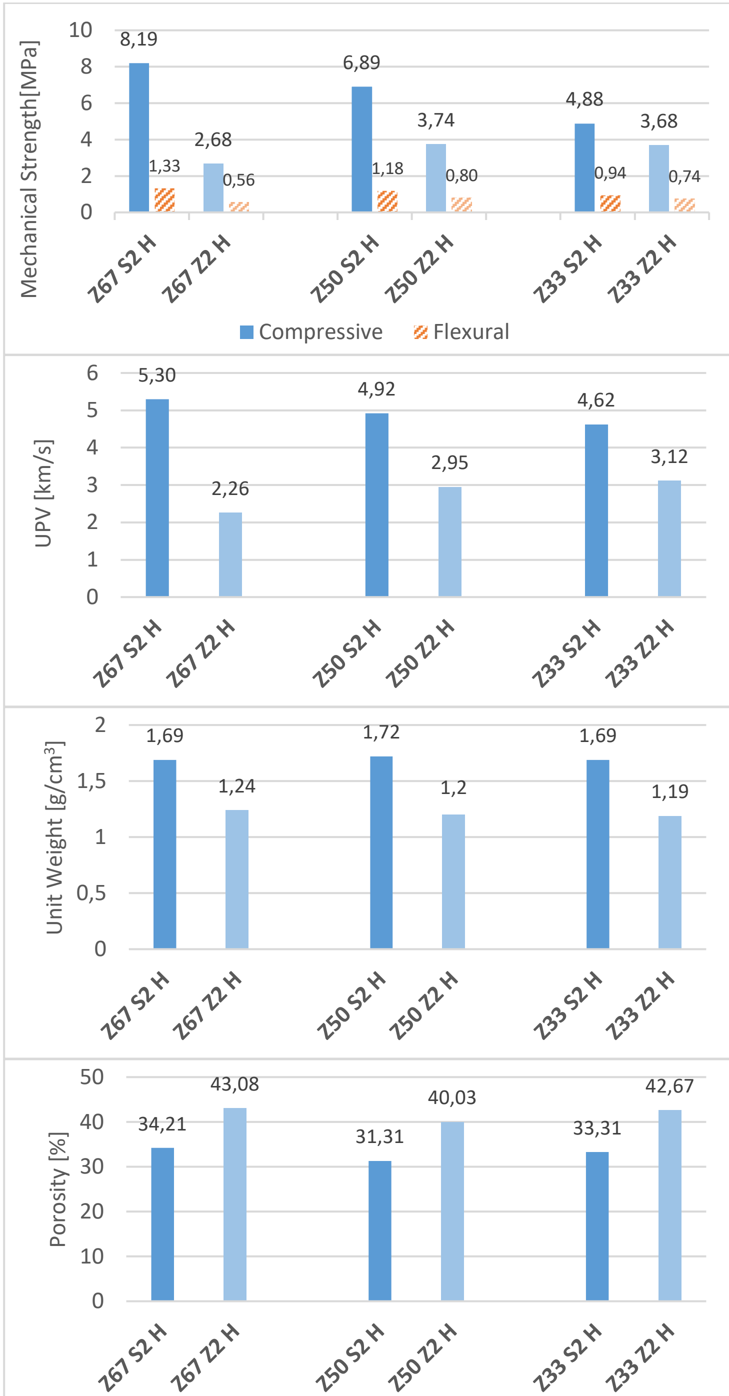

Fig. 3. Physical and mechanical test results of the samples with S2 and Z2 aggregates with different pozzolan/lime ratios.

3.1.2 Influence of aggregate type

When NZ aggregate of the same size (0-2 mm) was used instead of sand in the mortar, the compressive strength of Z67-Z2-H decreased to 33% of that of Z67-S2-H, resulting in 2.68 MPa; in Z50-Z2-H, it decreased to 54% of Z50-S2-H, resulting in 3.74 MPa; and in Z33-Z2-H, it decreased to 75% of Z33-S2, resulting in 3.68 MPa. Considering that the specific gravity ratio of NZ to sand is approximately 0.79, it can be understood that mortars with NZ aggregate are lighter and provide lower mechanical strength compared to those with sand. This trend is illustrated in Figure 3, where the decrease in ultrasonic pulse velocity (UPV) and unit weight values corresponds with the decrease in mechanical strengths, while porosity values increase.

On the other hand, as the pozzolan/lime weight ratio decreased, the change rate of compressive strengths of the mortars with zeolite aggregate was not the same as the rate with compressive strengths of mortars with sand. Compared to Z67-Z2-H, instead of a decrease in compressive strengths, increases of 1.40 times and 1.38 times were detected in Z50-Z2 and Z33-Z2, respectively. This suggests that NZ aggregate contributes to the pozzolanic reaction in the mortar. As a result of the pozzolanic reaction between hydrated lime, which increases towards Z33–Z2, and the NZ present in the binder as both aggregate and pozzolan, the strength increased by a factor of 1.40. Although Z50 and Z33 yield comparable mechanical strengths, Z33's similar porosity to Z67 may be attributed to the high porous structure resulting from excess hydrated lime that did not participate in the pozzolanic reaction with NZ. The highest mechanical strength among the studied binder alternatives using NZ aggregate was achieved with the mortar Z50-Z2-H, which has a lime/pozzolan ratio of 1/1, with compressive and flexural strengths of 3.74 MPa and 0.80 MPa, respectively.

3.1.3 Influence of NZ aggregate size

The effect of different NZ aggregate size distributions on the mechanical strength of mortar was examined on the Z50-coded zeolite-based lime mortars with the lime/pozzolan ratio of 1/1, which gave the highest mechanical strengths.

As the maximum aggregate grain size of NZ used in Z50 mortar increased from 2 mm to 4 mm and 7 mm, the compressive strengths decreased to 3.74, 2.17, and 1.56 MPa, respectively (Figure 4).

This decrease can be explained by the porous structure of the NZ aggregate and the voids formed due to the gap-graded granulometry of the 2 - 4 mm and 4 - 7 mm grain size distributions. In parallel with the mechanical strength results, with the increase of NZ aggregate size, the UPV and unit weight values of the mortars tended to decrease, while their porosity values increased as expected.

3.1.4 Influence of curing conditions

The compressive strengths obtained by curing the Z50-Z2, Z50-Z4, and Z50-Z7 mortars under the influence of heat (55°C and 95% RH) for 6 days were 3.74, 2.17, and 1.56 MPa, respectively. The compressive strengths of the same mortars obtained as a result of the steam curing (70°C and low pressure) for 6 hours were 2.55, 1.60, and 1.43 MPa, respectively.

As can be seen in Figure 4, the intended improvement in strength over a shorter time could not be achieved with the applied steam cure. Compared to heat curing, the compressive strengths decreased by 0.68, 0.74, and 0.91 times, respectively.

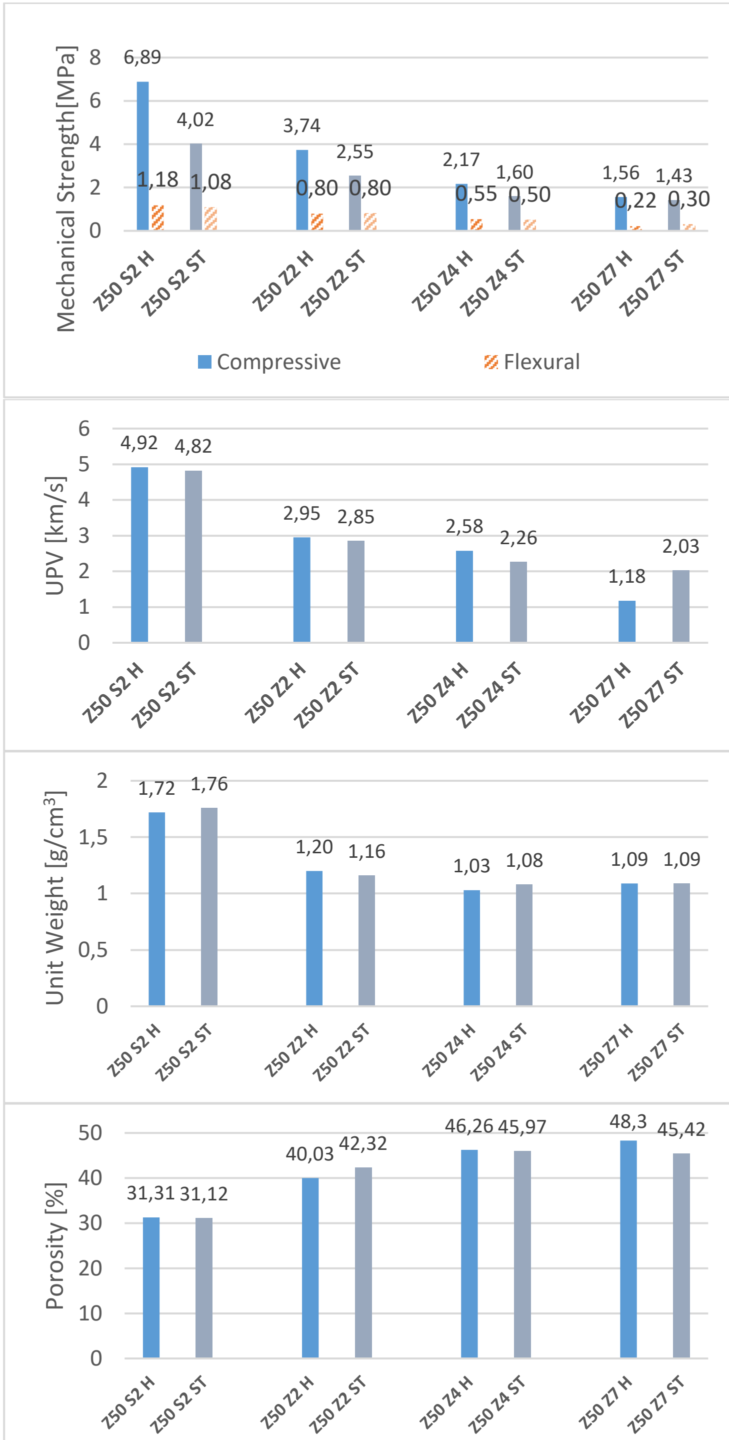

Fig. 4. Physical and mechanical test results of Z50 samples with different aggregate types, sizes, and different curing conditions.

As the aggregate size increased, the rate of loss in compressive strengths due to the effect of steam curing decreased, making this type of curing more advantageous for mortars with larger aggregate sizes. Indeed, under steam curing conditions, the UPV value of Z50 mortar with an aggregate grain size of 4–7 mm was found to be 1.72 times higher than that produced under heat curing conditions. This may demonstrate how the pozzolanic reaction between NZ and calcium hydroxide accelerates with steam curing, leading to the formation of calcium silicate hydrates (C-S-H), which fill the pores and voids in the mortar matrix. This densification decreases the mortar's total porosity.

Furthermore, a compressive strength of 2.55 MPa obtained in Z50-Z2 mortar, which can be considered a prefabricated product by applying steam curing, indicates the potential of obtaining a product of similar quality when compared to some other studies. In [27], the compressive strength obtained for the alkali-activated slag material was found to be 2.42 MPa, although the applied autoclave curing temperature and pressure (187 °C/11 bar) were higher. When sand was utilized as an aggregate in the Z50 binder, as is shown in Figure 4, the impact of steam curing compared to heat curing was also investigated, and it was found that the compressive strength of this mortar mixture dropped by 0.58 times.

3.2 Zeolite for Adsorption-Desorption Behavior

The process of gases, vapors, dissolved substances, and liquid molecules adhering to or accumulating on a solid surface, or concentration change, is termed ‘adsorption’, while the separation of adhering particles or molecules from the surface is called ‘desorption’. Adsorption is a superficial mechanism, whereas ‘absorption’ represents volumetric retention [28]. As a porous and adsorptive aggregate, zeolite was used in lime-based mortars to improve the moisture buffering behavior.

Samples with varying pozzolan-lime ratios with sand aggregate (Z67-S2-H / Z50-S2-H / Z33-S2-H) and NZ aggregate (Z67-Z2-H / Z50-Z2-H /Z33-Z2-H), the Z50-Z4-H coded sample with different aggregate sizes, and samples with a lime/pozzolan ratio of 1/1 at different curing conditions (Z50-Z2-ST/Z50-Z4-ST/Z50-Z7-ST) were subjected to adsorption-desorption cycles. Only Z50-Z7-H coded sample, which was damaged during de-molding process, was excluded from the experiment.

To determine the total adsorption amount of the samples, they were set to a constant cycle first, simulating optimum indoor thermal comfort conditions set at 24.4°C and 60% RH for five days. The results of this five-day measurement are given in Figure 5, where Δg% indicates the percentage of the weight increase of the samples.

According to these results, for the samples prepared with sand, the total adsorption percentage increased in parallel with the increasing pozzolan ratio in the mortar (Z67: 2,13% >Z50:1,86% >Z33:1,57%).

When comparing the different aggregate types, the Z33-Z2-H coded sample adsorbed 6.09% moisture by weight, while the Z33-S2-H coded sample absorbed 1.57%. Later in this review, the adsorption rates of the samples are as follows: Z67-Z2-H:4.49%, Z67-S2-H:2.13%, Z50-Z2-H:5.57%, Z50-S2-H:1.86%, Z50-Z4-H:5.05%.

The adsorption values of mortars produced with NZ aggregate increased by 2.10 times in Z67 and 2.99 times in Z50 compared to the mortars with sand. On the other hand, when the aggregate size was increased to 4 mm, there was a 1.10 times decrease.

Comparing the curing conditions, samples with heat cure show better adsorption performance than the steam cure samples. The Z50-Z2-H coded sample has a 1.18 times higher moisture adsorption rate than Z50-Z2-ST, while the Z50-Z4-H coded sample has a 1.02 times higher moisture adsorption rate than Z50-Z4-ST.

Considering all the NZ aggregate samples, the Z33-Z2-H has the maximum adsorption rate at 6.09%, while the Z67-Z2-H coded sample has the minimum adsorption rate at 4.49%.

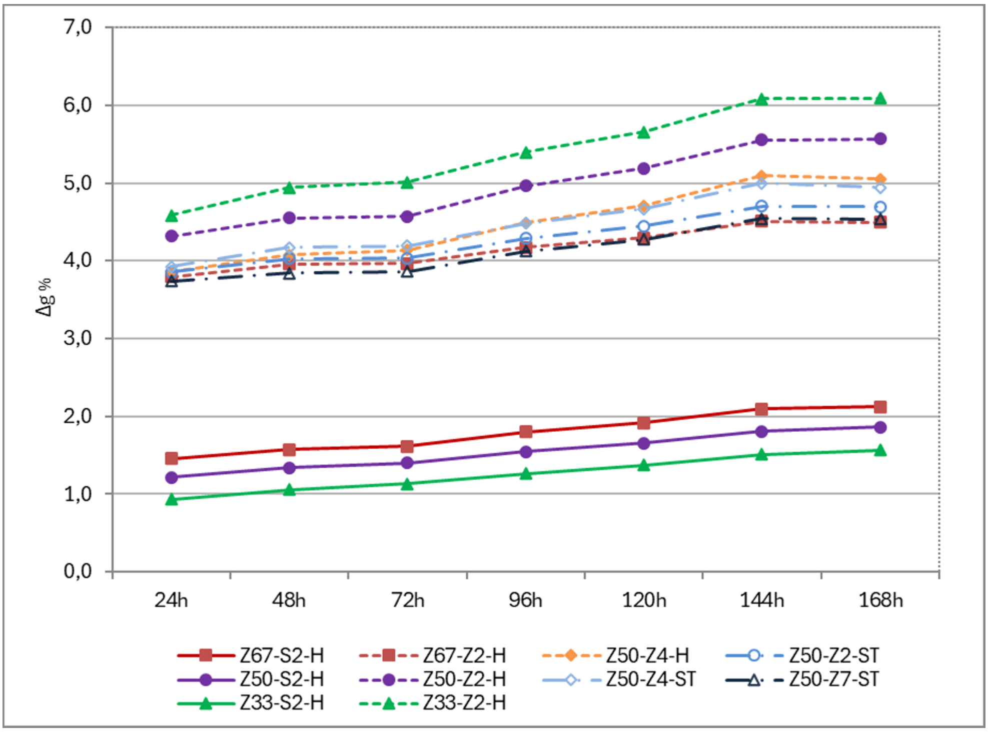

Fig. 5. Total adsorption of the samples at constant cycle after 24.4 °C - 60% RH for five days.

To determine the adsorption-desorption behavior of the samples, fluctuating humidity and temperature conditions were set. The simulated environments alternated between cycles of 8 hours at 30.1°C - 85% RH and 16 hours at 24.4 °C - 60% RH, respectively. Samples were monitored for seven days in the environmental chamber, and the results of the measurements are given in Figure 6 as Δg%, which indicates the percentage of the cumulative weight increase and decrease of the samples.

According to these results, under fluctuating humidity and temperature conditions, samples prepared with sand have a lower adsorption-desorption percentage than samples prepared with NZ aggregate. The weight increases resulting from adsorption-desorption cycles of the sand aggregate samples are Z33-S2-H:1.00%, Z50-S2-H:0.83%, and Z67-S2-H:0.82%. Z67-S2-H and Z50-S2-H coded samples have almost the same value for adsorption-desorption. The replacement of sand with zeolite aggregate led to an increase in the adsorption-desorption values. The adsorption-desorption weight increases of the samples prepared with NZ aggregate are Z50-Z2-H: 1,87% and Z67-Z2-H:1.73% (Figure 7).

The effect of NZ aggregate size distributions and curing conditions on the adsorption-desorption behavior of the mortar was examined by studying Z50 - coded zeolite-based lime mortars in Figure 8. While the lowest adsorption fluctuation belongs to the Z50-S2-H (0.837%) sample, which is produced with sand, the highest adsorption-desorption fluctuation belongs to the Z50-Z4-H (2.07%) sample, which comprises zeolite as aggregate. Samples prepared with steam curing show almost the same performance as the heat-cured pairs, with slight decrease aligned with the change of aggregate size rising from 2 mm to 4 mm (Z50-Z4-H: 2.07% ; Z50-Z4-ST:1,99% ; Z50-Z2-H: 1.87%; Z50-Z2-ST:1.88%).

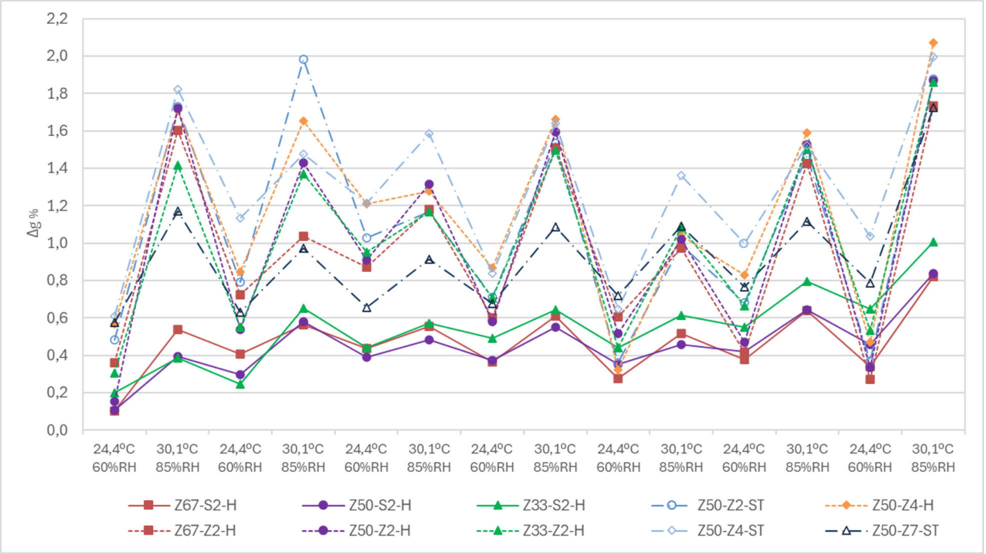

Fig. 6. Moisture adsorption-desorption weight differences of all zeolite-lime mortar samples after cycles of alternating temperature and humidity conditions.

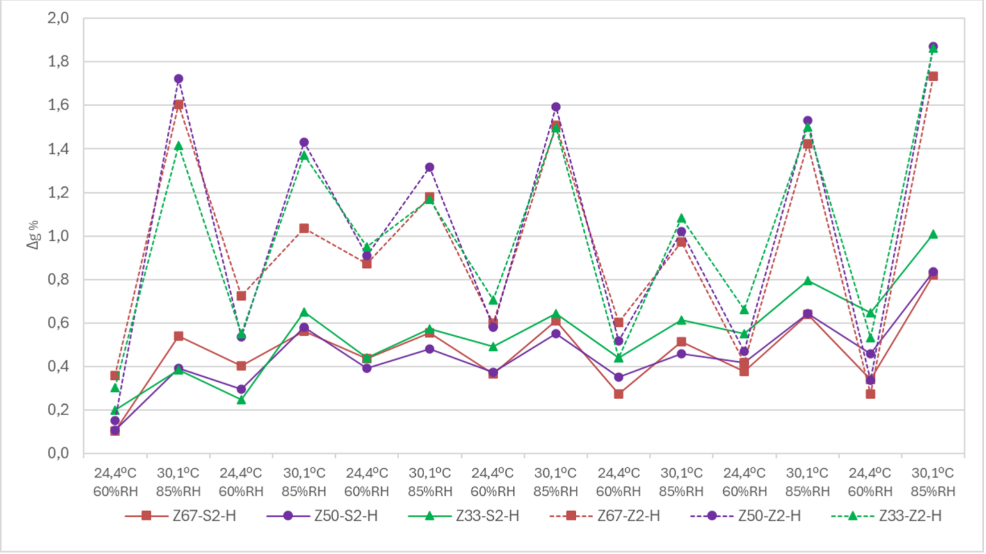

Fig. 7. Moisture adsorption-desorption weight differences of the zeolite-lime mortar with different aggregate types after cycles of alternating temperature and humidity conditions.

Despite increasing the aggregate size (7 mm), the minimum adsorption-desorption fluctuation is exhibited by the Z50-Z7-ST (1.72%). However, it is suspected that the samples prepared for this test were partially damaged during the measurements. Thus, repeating this test in the future should be considered.

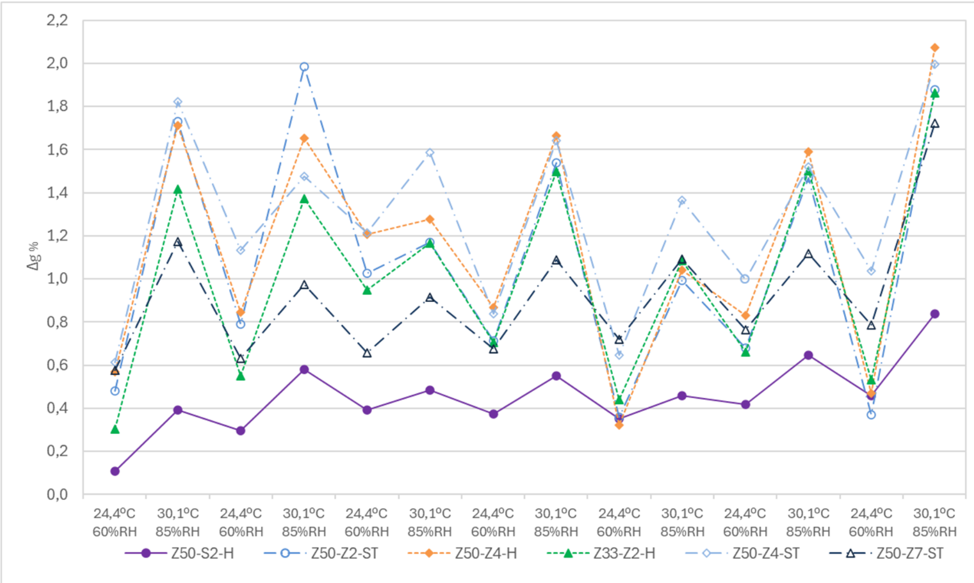

Fig. 8. Adsorption-desorption weight differences of the Z50 coded sample with different aggregate types, sizes, and curing conditions after cycles of alternating temperature and humidity.

4 Conclusions

In this study, natural zeolite-based lime mortar alternatives with different pozzolan/lime ratios, curing conditions, and aggregate sizes are investigated through the combination of physical and mechanical testing methods. The highlights of the study can be summarized as follows:

- The NZ material, analyzed using the TS 25 method, exhibits pozzolanic activity. Considering the mechanical properties of the produced pozzolanic zeolite-lime mortars, they can be utilized as a building mortar.
- Lime mortars containing different amounts and particle sizes of NZ adsorb/desorb moisture in the conditioned environment. The data obtained indicate that NZ can be used in the production of finishing building materials with moisture buffering behavior.
- Increasing the ratio of sub-50 micron NZ used in the binders of mortars as pozzolan with sand aggregate gave positive results in terms of improving both mechanical strength and moisture buffering behavior.
- In mortars where NZ was used as aggregate, better moisture buffering behavior was obtained compared to samples with sand aggregate, but mechanical strength decreased.
- NZ aggregate with continuous particle size distribution between 0-2 mm enhanced the results in terms of both mechanical strength and moisture buffering behavior for the constant cycle compared to two gap-graded aggregates, 2 – 4 mm and 4 - 7 mm aggregate size distribution. On the other hand, under the fluctuating temperature and humidity cycle, 2-4 mm NZ aggregate samples performed enhanced results in terms of moisture buffering behavior.
- The desired efficiency could not be obtained from the applied steam cure, and all samples cured with steam suffered a decrease in compressive strength compared to the heat cure. It was observed that the zeolite aggregate samples cured by steam had

not yet completed their curing to a large extent. Nevertheless, it is considered that the mechanical properties experienced in this study can be improved by testing different parameters such as time and temperature of steam cure in future studies.

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