Investigation of the Properties of Masonry Mortar Containing Recycled Aggregate and Zeolite with a Focus on Sustainable Development and Green Mortar

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ABSTRACT

In this article, the characteristics of masonry mortar made with recycled sand and zeolite are investigated in the context of sustainable development. For this purpose, 8 masonry mortar mix designs were considered, in which, in addition to the base design, recycled sand replaced natural sand by 50% and 100%, and zeolite replaced cement by 10%, 15%, and 25%. Additionally, the water-to-cement weight ratio was set at 0.55, and the cement-to-sand weight ratio was set at 1:3. Experiments were designed to measure various physical and mechanical properties of the masonry mortar made with recycled sand and zeolite. Tests for water absorption and density were conducted to evaluate physical properties, as well as tests for compressive strength and flexural strength to assess mechanical properties, and a flow table test to evaluate workability and efficiency. The tests performed on the masonry mortars made with recycled sand and zeolite have yielded acceptable results that meet the requirements of the national standard for masonry mortar. They demonstrate that replacing 50% of natural sand with recycled sand and 15% of cement with zeolite can be a good strategy for reducing the use of natural materials, promoting sustainable development, and achieving green mortar.

Keywords: Recycled Sand, Zeolite, Sustainable Development, Green Mortar, Masonry Mortar

1. INTRODUCTION

Cement is one of the most fundamental components of concrete and mortar, which is why it is produced in significant volumes worldwide. A report published by the United States Geological Survey in 2010 stated that approximately 2 billion tons of Portland cement were produced globally in 2010, leading to the production of 12 to 14 billion tons of concrete and masonry mortar. On the other hand, cement production is associated with numerous environmental issues; therefore, it is essential to address them appropriately to reduce the environmental degradation caused by its unrestrained production. The cement production process consumes a great deal of energy, to the extent that the production of cement clinker occurs at temperatures close to 1450 degrees Celsius. Cement factories, after power plants, are the second-largest producers of greenhouse gases such as carbon dioxide [1]. Generally, the production of one ton of cement results in the production of one ton of carbon dioxide, and the cement industry accounts for 9% of the total carbon dioxide emissions globally; hence, the biggest concern regarding environmental issues in cement production is to reduce the greenhouse gases produced in this process as much as possible. One of the global efforts to reduce environmental pollution caused by cement production is the use of alternative materials to cement [2].

One suitable alternative to cement can be natural zeolite, a hydrated aluminosilicate of alkaline and alkaline earth cations, which has been widely used in constructions since ancient times [3]. However, its application as a popular type of natural pozzolan in the production of pozzolanic cements began in the early twentieth century and has shown a growing trend since then. Zeolite contains a significant amount of active SiO_2 and Al_2O_3, which chemically combine with calcium hydroxide produced by cement hydration to form C-S-H gel and additional aluminates, thereby improving the hardened cement's microstructure. Research on zeolite-containing concretes has demonstrated an increase in the strength of these concretes. The use of zeolite as a pozzolanic additive with a high absorption percentage (close to 40% of its weight) creates internal curing in concrete, resulting in low permeability and high durability at a low water-to-cement ratio. Moreover, zeolite-containing concretes exhibit much better environmental performance compared to cement, such that replacing 20% of cement with zeolite can reduce the concrete's global warming index by up to 70% [4]. This justifies the use of zeolite from a sustainable development perspective.

In recent years, due to the increasing use of natural materials and resources in construction and the rising demand for concrete, access to natural aggregate materials has become more difficult. On the other hand, with the demolition of old structures, the need for disposal sites for construction debris has significantly increased, leading to environmental pollution and the occupation of suburban areas with construction debris. In many countries, due to the filling up of surrounding urban spaces and the lack of suitable sites for the burial of construction debris, construction waste has become a fundamental problem [5]. Additionally, the natural resources required for new construction are becoming scarcer day by day, and accessing them is becoming more challenging. An appropriate and sustainable development-based solution is the use of construction waste for new construction, which can alleviate the need for natural materials and reduce pollution caused by the burial of construction waste. In this regard, extensive research has been conducted in recent years, and many countries have developed regulations and guidelines for concrete recycling and use in construction and masonry [6].

From an environmental perspective, the use of recycled fine aggregate as sand and gravel can have several advantages, including: (1) reducing the extraction of sand and gravel, which has significant environmental impacts worldwide; (2) reducing energy consumption and carbon dioxide emissions; and (3) preventing the illegal disposal of recycled material fractions.

Researchers are increasingly focusing on innovation in green concrete and their environmental performance throughout their lifecycle. While recycled aggregate concrete is a type of green concrete, researchers have endeavored to explore strategies to make it greener. Various types of waste or leftover materials are employed in the composition of recycled aggregate concrete, and the number of lifecycle assessment studies has increased over the past decade [7]. This research investigates the physical and mechanical properties of recycled aggregate concrete made with recycled sand and zeolite as alternative materials to cement, which is widely used in civil engineering works. Utilizing recycled materials in this field can save valuable natural resources and allow for the use of natural materials in more sensitive areas that require high-quality and consistent materials. Moreover, it reduces the need for vast areas of land around cities for the disposal of construction debris, which is currently becoming a major issue in large cities. Additionally, in sustainable development studies, the replacement of cement with zeolite leads to a reduction in energy consumption and greenhouse gas emissions (global warming index). In previous studies, some characteristics of recycled sand and zeolite, such as particle size distribution, have varied, which can significantly affect the properties and characteristics of the resulting mortars. Therefore, to reduce the variables affecting the test results, uniform particle size distribution was used for both natural and recycled sand in the present study. Furthermore, the performance of all masonry mortars was limited within a specific range, and to prevent the effects of moisture changes in materials, saturated surface dry aggregates were used.

2. Materials and Mixing Design

2.1. Characteristics of Materials

In this research project, Type 2 Portland cement obtained from the Tehran Cement Factory has been utilized. This type of cement is suitable for applications requiring moderate heat of hydration and resistance to sulfates. The natural sand used in this study is of river origin with a maximum particle size of 4.75 millimeters. Recycled sand is obtained from the crushing of existing concretes in locations designated for the disposal of construction debris and, after sieving, is brought to the required sizes. Table 1 presents the characteristics of the concrete containing recycled sand.

Table 1. Characteristics of natural aggregate materials

Characteristics	Value
Water/Cement	340.
Cement (kg/m3)	420
Water (kg/m3)	8/142
5.9 mm (kg/m3) - 19 Aggregate	335
Aggregate 4.75 - 12.5 mm (kg/m3)	258

Table 2 provides the technical specifications of the aggregates used. Investigations have shown that the water absorption of recycled sand is significantly higher than that of natural sand, which may be attributed to the different physical and chemical properties of recycled sand. Recycled sands typically have more diverse absorption surfaces, possibly due to the presence of various surfaces with different absorption properties. Additionally, the apparent density of recycled sand is lower than that of natural sand, which may be primarily due to the presence of hydrated cement particles attached to the surfaces of recycled sand.

Table 2. Characteristics of recycled aggregate fines

Characteristic	Water Absorption (%)	Density (Ton/m3)
Coarse Aggregate	41.3	51.2
Fine Aggregate	39.12	28/2

The zeolite used in this study is sourced from a production facility located in Semnan. Table 3 presents the chemical analysis results of Portland cement and zeolite, while Table 4 lists the compositions present in the recycled sand used.

Table 3. Chemical composition analysis of used materials

Chemical Composition (%)	Cement	Zeolite
SiO2 (%)	27.30	64.9
Al2O3 (%)	4.60	12.3
Fe2O3 (%)	2.70	0.36
CaO (%)	46.70	0.1
MgO (%)	3.50	0.9
SO3 (%)	2.04	0.79
Na2O (%)	0.34	
K2O (%)	0.52	
Equivalent Alkali (%)	0.68	
LOI (%)	4.84	4.18

Table 4. Constituents of recycled sand

Component	Weight Percentage (%)
Concrete and Cement	94.32
Clinker and Brick Particles	2.27
Other Mineral Materials	2.04
Asphalt	0.76
Ceramic Materials	0.34
Other Materials	0.27

The fine aggregate used in this project was obtained from the aggregate sources, and the particle size distribution of it was determined according to ASTM C144 standards [8]. The particle size distribution of recycled fine aggregate was analyzed separately, and based on the desired grading, the particle size distribution was adjusted accordingly. The fine aggregate was divided into several size ranges, including 0-0.5, 0.5-0.150, 0.150-0.300, 0.300-0.630, 0.630-1.180, 1.180-2.360, and 2.360-4.750, and then mixed with each other in specified weight proportions to meet the particle size distribution requirements specified in ASTM C144 standard. Prior to the adjustment of particle size distribution, natural sand was coarser, and recycled sand was finer. After the adjustment of particle size distribution, they both fell within the acceptable range of the standard. Figure 1 illustrates the changes in particle size distribution.

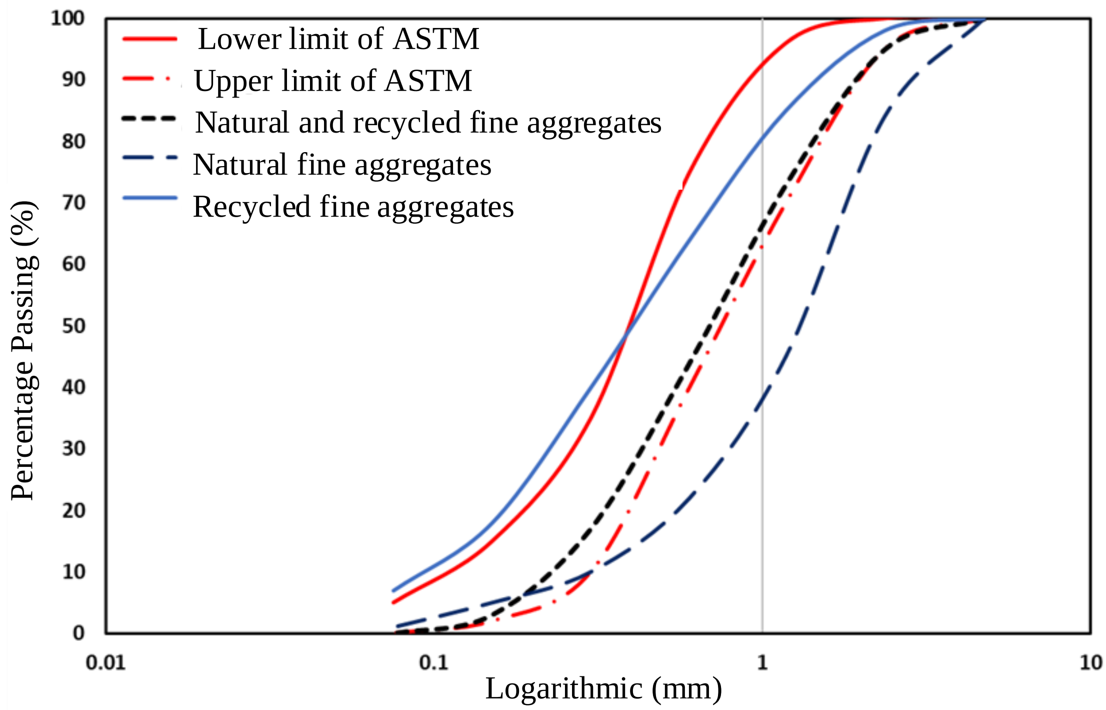

Fig. 1. Particle Size Distribution Analysis of Fine Aggregate from Natural and Recycled Sources within ASTM C 144 Grading Ranges

2.2. Mixing Design

In this study, one reference sample without using zeolite and recycled aggregates and seven different samples using zeolite as a substitute for cement and recycled aggregates instead of natural aggregates have been considered (Table 5). These samples were prepared with different percentages of zeolite substitution at 10%, 15%, and 25%, and recycled aggregates at 50% and 100%. Based on the results of the flow table test, the water-to-cement ratio for the reference sample was determined to be 0.55. In this sample, the ratio of cementitious materials to sand was considered as 1:3. Due to the high water absorption percentage by recycled aggregates and the possibility of error in preparing mortar mixtures, both types of sand were saturated with a dry surface in this study. For this purpose, the required amount of sand for each sample was saturated in water 24 hours before, and two hours before preparing the samples, natural and recycled sands were brought to a state of saturation with a dry surface using heating devices such as a hairdryer, as well as by shaking. The mixing process was carried out at a temperature of 25±2 degrees Celsius. Finally, the samples were removed from the molds after 24±2 hours and placed in a water and lime solution for curing.

Table 5. Prepared Mixing Designs

Mixing Design	NM	10ZM	RM-50	RM-100	10ZRM-50	10ZRM-100	15ZRM-50	25ZRM-50
Cement (kg/m3)	450	405	450	450	405	450	382/5	382/5
Zeolite (kg/m3)	0	45	0	0	45	45	67/5	112/5
Water (kg/m3)	274.5	274.5	274.5	274.5	274/5	274/5	274/5	274/5
Water/Cement	0/55	0/55	0/55	0/55	0/55	0/55	0/55	0/55
Saturated Natural Fine Aggregate (kg/m3)	1350	1350	675	0	675	0	675	675
Saturated Recycled Fine Aggregate (kg/m3)	0	0	675	1350	675	1350	675	675

2.3. Research Method and Mortar Testing

The mortar tests are conducted in both fresh and hardened states. Below is a summary of the designed experiments for the research:

2.3.1 Mixing Design

The bulk density of mortars is measured according to standard EN 1015-6 [9].

2.3.2 Properties of Hardened Mortar

In this study, the compressive and flexural strength of concrete specimens that have hardened are assessed according to standard EN 1015-11 [10, 11] at ages 7 and 28. The water absorption coefficient test is also conducted as follows: initially, the specimens are kept in water at a temperature of 25±2°C for 24 hours, then the weight in the saturated surface-dry state is measured, and finally, they are dried at a temperature of 110±5°C to measure their dry weight. The bulk density of mortars is measured using standard EN 1015-10 [9]. The dimensions and number of specimens used in the experiment are presented in Table 6.

Table 6. Number and dimensions of test specimens

Test	Number of Test Specimens	Dimensions of Specimen
Water Absorption	3	160 * 40 * 40 mm
Bulk Density	3	160 * 40 * 40 mm
Flexural Strength	3	40 * 40 mm
Compressive Strength	6	40 * 40 mm

3. Results and Discussion

3.1. Workability and Setting Time of Fresh Mortar

The workability values for the base sample and mixtures with 50% and 100% replacement of natural aggregate with recycled aggregate were obtained as 178, 172, and 163 millimeters, respectively. The analysis of the results indicates that despite considering a constant water-to-cement ratio and the use of saturated surface-dry recycled sand, the workability of fresh mortar decreases with increasing replacement ratio of natural sand with recycled sand. Substituting 50% of natural sand with recycled sand does not show a significant change in the workability of fresh mortar, but with more than 50% replacement, the workability of fresh mortar starts to decrease more rapidly. Among the reasons for the decrease in workability in mortar made with recycled sand, mention can be made of its more angular shape and greater surface roughness compared to natural sand. For instance, in the case of 100% recycled sand, the workability of fresh mortar decreases by 24.8%. These results are presented in Figure 2a.

Furthermore, in the case of substituting 10% zeolite in mixtures with 0%, 50%, and 100% recycled aggregate, the workability values were obtained as 178, 176, and 170 millimeters, respectively. In the mixture with 100% recycled aggregate, the workability of fresh mortar decreases by 49.4%. These values indicate a lower reduction compared to mixtures solely with recycled aggregate. These results are observable in Figure 2b. Additionally, considering the flow table values for zeolite replacement percentages ranging from 0% to a specific value (10% to 25%) alongside a constant 50% recycled aggregate and other concrete constituents, the workability initially increases and then decreases with increasing zeolite replacement. These results are scrutinizable in Figure 2c. Moreover, Table 7 provides the workability values for all mixtures.

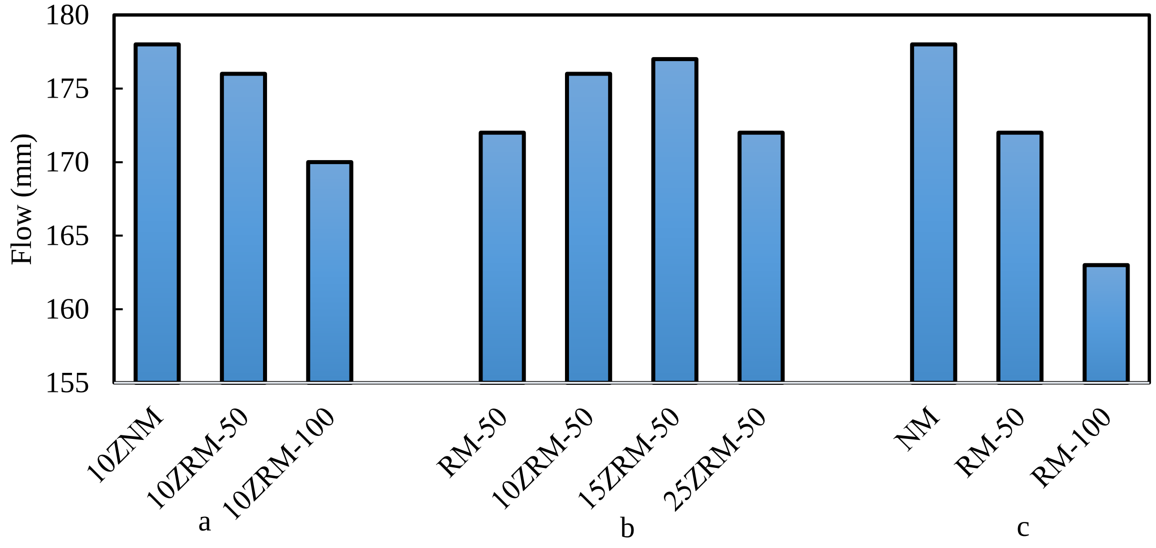

Fig. 2. Comparison of flow values with increasing substitution levels: (a) Recycled sand in zeolite-containing design, (b) Zeolite in designs with equal amounts of natural and recycled sand, (c) Recycled sand in the base design

One of the essential components for mortar is its setting time. Setting time indicates how long a mortar can be used in construction works with a reasonable amount of energy expenditure. Naturally, as time passes, the setting time decreases. According to the standard definition, setting time is defined as the time it takes for the workability of fresh mortar to decrease by 30 millimeters compared to the initial workability measurement taken 10 minutes after the start of mixing.

The setting time for the base sample made with natural sand and with 50% and 100% replacement rates of recycled aggregate was calculated as 22.52 and 17.21 minutes, respectively. It can be observed that with a 50% increase in the replacement rate of recycled aggregate with natural sand, there is a decrease of approximately 23% in the setting time. These results are depicted in Figure 3a. Additionally, in the case of substituting 10% zeolite in mixtures with 0%, 50%, and 100% recycled aggregate, the setting time values were obtained as 21.5, 18.2, and 14.1 minutes, respectively. In the mixture with 100% recycled aggregate, the setting time of fresh mortar decreases by 34.42%. These values indicate a lower reduction compared to mixtures solely with recycled aggregate. These results are observable in Figure 3b. Furthermore, considering the flow table values for zeolite replacement percentages ranging from 0% to a specific value (10% to 25%) alongside a constant 50% recycled aggregate and other concrete constituents, a decreasing trend in setting time is observed again. These results are scrutinizable in Figure 3c. Additionally, Table 7 provides the setting time values for all mixtures.

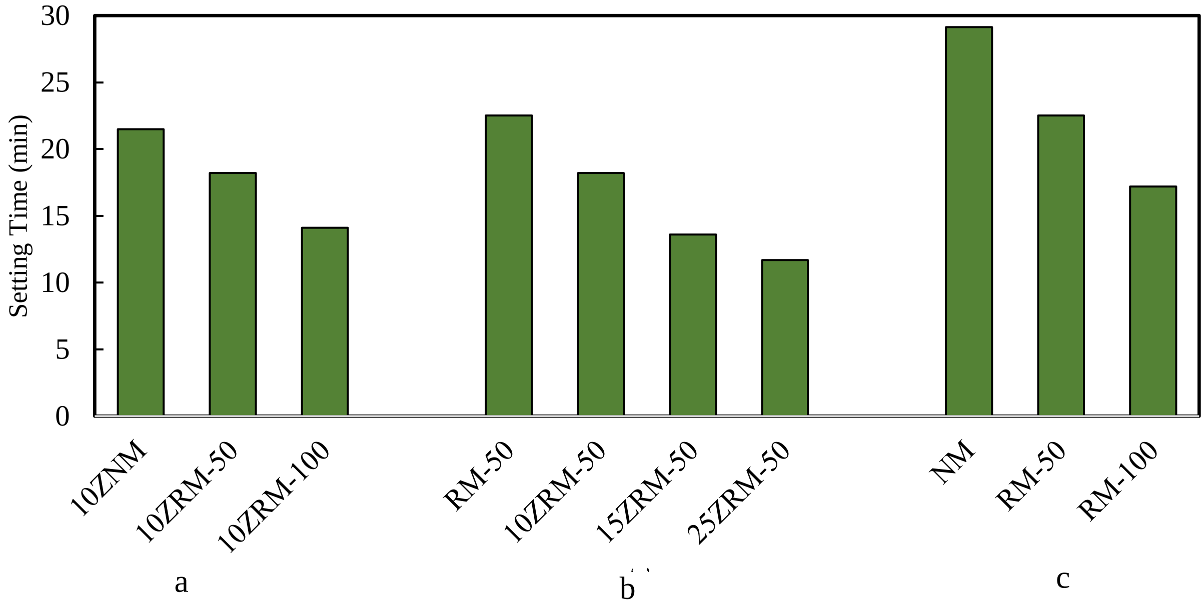

Fig. 3. Comparison of flow values with increasing substitution levels: (a) Recycled sand in zeolite-containing design, (b) Zeolite in designs with equal amounts of natural and recycled sand, (c) Recycled sand in the base design

Table 7. Results of tests related to fresh and hardened mortar

Test	Fresh Mortar Bulk Density	Hardened Mortar Bulk Density	Water Absorption	Flow of Fresh Mortar	Setting Time of Fresh Mortar
	(Ton/m^3)	(Ton/m^3)	(%)	(mm)	(min)
NM	2.11	2.12	6.96	178	29.14
10ZNM	2.12	2.15	6.36	178	21.5
RM-50	1.91	2.03	8.46	172	22.52
RM-100	1.84	1.89	9.36	163	17.21
10ZRM-50	1.93	1.97	8.17	176	18.2
10ZRM-100	1.83	1.94	7.02	170	14.1
15ZRM-50	1.95	2.02	8.79	177	13.6
25ZRM-50	1.95	1.98	8.15	172	11.7

3.2. Bulk Density of Fresh and Hardened Mortar

In this study, the bulk density of freshly prepared mortar made with natural sand and replacement percentages of 0%, 50%, and 100% with recycled aggregate was calculated as 2.11, 1.91, and 1.84 Ton/m^3, respectively. Additionally, the bulk density of hardened mortar was calculated for mixtures made with natural sand and replacement percentages of 0%, 50%, and 100% with recycled aggregate as 2.12, 2.03, and 1.89 Ton/m^3, respectively. The investigation of experimental results demonstrates that overall, with an increase in the replacement ratio of natural sand with recycled aggregate, both the bulk density of fresh and hardened mortar decreases. One of the reasons for the decrease in bulk density in mortars made with recycled aggregate is the higher porosity of recycled aggregate compared to natural sand. Moreover, the sharp-edged nature and rough surface of recycled aggregate result in an increase in entrapped air within the mortar, consequently leading to a decrease in bulk density. Additionally, it can be found from the extracted results that an increase in zeolite substitution in the bulk density of both fresh and hardened mortar has little effect, which can be attributed to the close density of cement to zeolite, as each amount of cement has been replaced by the same amount of zeolite. The results of this section are presented in Table 7.

3.3. Water Absorption Percentage of Hardened Mortar

The water absorption percentage of hardened mortar was measured for the base sample and replacement percentages of natural sand with recycled aggregate at 0%, 50%, and 100% as 96.6%, 46.8%, and 36.9%, respectively. Considering the significant difference in water absorption coefficients between natural sand (41.3%) and recycled aggregate (39.12%), the results obtained in this experiment confirm this. The examination of results indicates that at a replacement percentage of 100%, water absorption increases by 4.2%. The water absorption percentage of hardened mortar was measured for samples with equal amounts of natural and recycled sand and replacement percentages of zeolite at 0%, 10%, 15%, and 25%, yielding 46.8%, 17.8%, 49.8%, and 15.8%, respectively. The analysis of results shows that zeolite substitution has little effect on the water absorption percentage of hardened mortar. The results of this section are provided in Table 7.

3.4. Compressive Strength

Compressive strength testing was conducted on specimens broken in the flexural strength test. The compressive strength of the 7-day base sample made with natural sand was estimated at 18.24 MPa, and with an increase in the percentage of natural sand replacement with recycled sand to 50% and 100%, the compressive strength reached 14.56 MPa and 12.08 MPa, respectively, indicating a 20% and 33% reduction in compressive strength, respectively. Therefore, an increase in the amount of recycled aggregate correlates directly with a decrease in compressive strength. Consequently, on average, for each 10% replacement of natural sand with recycled sand, a 3.3% decrease in compressive strength of the 7-day sample is observed. The compressive strength of the 28-day base sample made with natural sand was estimated at 28.83 MPa, and with an increase in the percentage of natural sand replacement with recycled sand to 50% and 100%, the compressive strength reached 26.99 MPa and 22.39 MPa, respectively, indicating a 6.4% and 22.3% reduction in compressive strength, respectively (Figure 4a). Therefore, increasing the amount of recycled aggregate correlates directly with a decrease in strength. By comparing the strength reduction between the 7-day and 28-day samples, it can be observed that the decrease in strength is greater for the 7-day samples than for the 28-day samples.

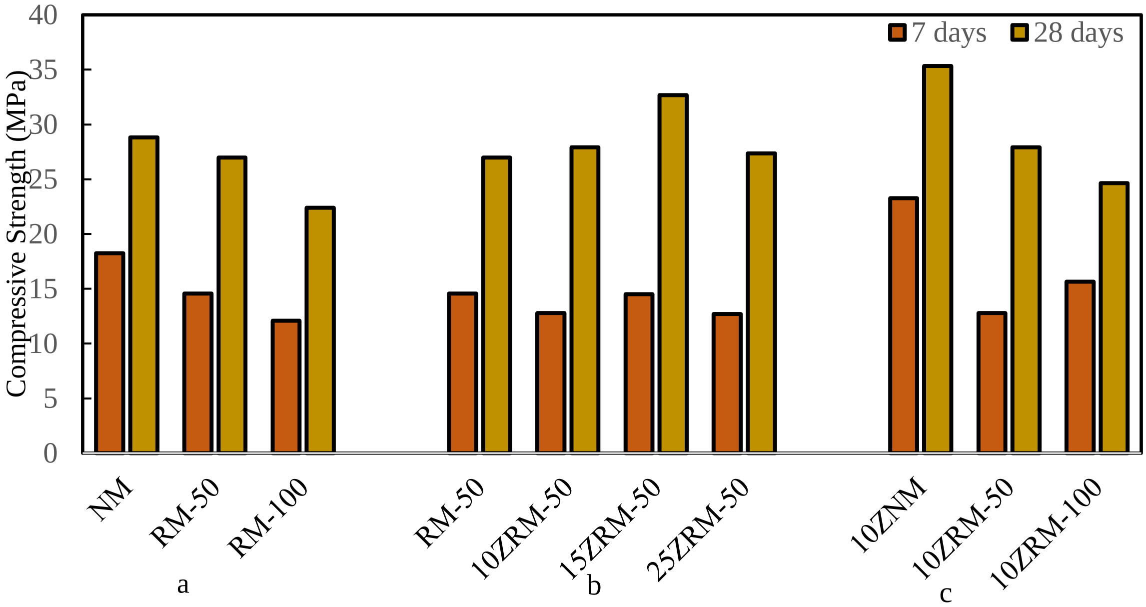

Fig. 4. Compressive strength of 7 and 28 day mortar specimens with increasing substitution (b) zeolite in the scheme containing equal amounts of natural and recycled sand, and (c) recycled sand in the scheme containing zeolite

The compressive strength of the 7-day samples made with an equal ratio of natural and recycled sand (without zeolite) was estimated at 14.56 MPa. With an increase in the percentage of cement replacement with zeolite to 10%, 15%, and 25%, the compressive strength decreased to 12.08, 14.5, and 12.7 MPa respectively, indicating reductions of 12%, 4.0%, and 8.12% respectively. The compressive strength of the 28-day samples made with an equal ratio of natural and recycled sand (without zeolite) was estimated at 26.99 MPa. With an increase in the percentage of cement replacement with zeolite to 10%, 15%, and 25%, the compressive strength decreased to 27.9, 23.68, and 27.36 MPa respectively, indicating reductions of 3.37%, 21.08%, and 37.1% respectively (Figure 4b).

A similar trend to Figure 4-a was observed for the decrease in compressive strength of the 7-day and 28-day samples with constant zeolite content due to an increase in the replacement of recycled sand, indicating that the presence of zeolite also has a detrimental effect on the compressive strength of both 7-day and 28-day samples (Figure 4c). However, the presence of zeolite has increased the compressive strength of the 7-day and 28-day samples compared to those without zeolite (Figure 4-a), which can be attributed to the filler and pozzolanic role of zeolite.

Therefore, the optimal design in terms of both strength and environmental sustainability (green concrete) can be found in the mix with 15% zeolite replacement for cement and 50% recycled sand replacement for natural sand (15ZRM-50). The reason for the optimal strength performance can be attributed to the pozzolanic and filler functions of the replaced zeolite and the internal action of the replaced recycled aggregate. The environmental sustainability improvement arises from using zeolite instead of a portion of cement and using recycled sand instead of half of the natural sand.

In addition to the above, the significant difference in the 28-day strength of this mix compared to the mix without zeolite (RM-50), which had similar strength at 7 days, can be attributed to the delayed reaction of zeolite (pozzolanic reaction). This same reason can also explain the lack of difference in the 7-day compressive strength of the three mixes containing zeolite in Figure 4-b compared to the mix without zeolite.

The compressive strength of the produced samples meets at least the minimum requirements of the National Iranian Standards regulations [12] and all fall within the 20 MPa strength category (the highest strength classification for masonry mortar in Iran), indicating high-quality mortar production. The cement-to-sand ratio of 1:3 leads to an increase in the 28-day compressive strength of masonry mortar, such that, according to the Iranian National Standard, compressive strength between 1 and 20 MPa is considered for masonry mortar. Nevertheless, considering the cement-to-sand ratio of 1:3 and 100% replacement of natural sand with recycled sand, it is still possible to achieve the highest strength category specified in the Iranian National Standard (mortar for masonry work).

3.5. Flexural Strength

The analysis of the results obtained at both 7 and 28 days shows that with an increase in the percentage of natural sand replaced by recycled sand and an increase in the percentage of cement replaced by zeolite, similar to the results obtained for compressive strength, flexural strength changes. These results are consistent with previous research findings [13]. In the 7-day samples, the flexural strength of the base sample made with natural sand was estimated at 4.85 MPa, and for replacement percentages of 50% and 100% of natural sand with recycled sand, the flexural strength was estimated at 4.2 and 3.27 MPa, respectively. These values indicate a

13% and 33% decrease in flexural strength, respectively. For the 28-day samples, the flexural strength of the base sample made with natural sand was estimated at 5.59 MPa, and for replacement percentages of 50% and 100% of natural sand with recycled sand, the flexural strength was estimated at 4.73 and 3.81 MPa, respectively. These values indicate a 15% and 32% decrease in flexural strength, respectively (Figure 5a).

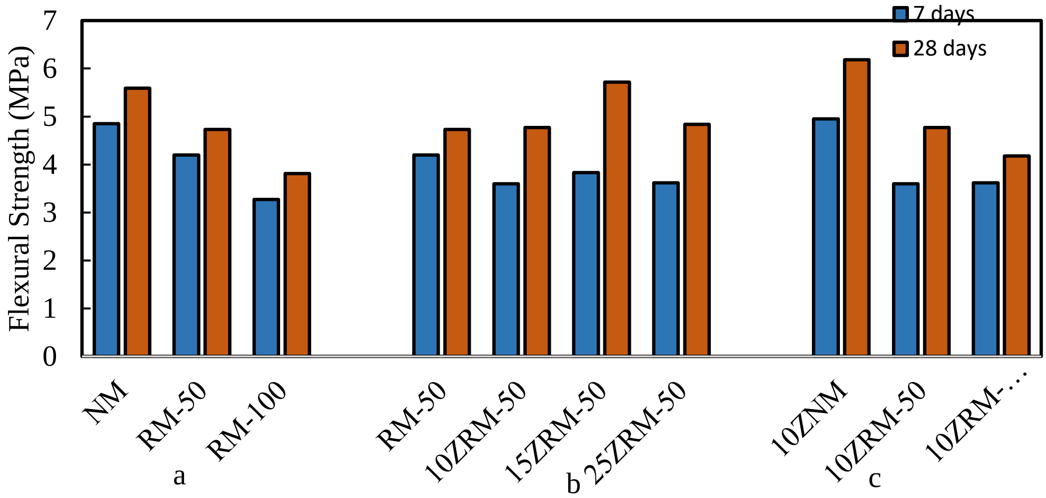

Fig. 5. Flexural strength of 7 and 28-day mortar specimens with increasing substitution of (a) recycled sand in the base scheme, (b) zeolite in the scheme containing equal amounts of natural and recycled sand, and (c) recycled sand in the scheme containing zeolite

The flexural strength of the 7-day samples, made with equal proportions of natural and recycled sand (without zeolite), was estimated at 4.2 MPa, and with an increase in the percentage of cement replacement with zeolite to 10%, 15%, and 25%, the flexural strength reached 3.63, 3.83, and 3.62 MPa, respectively, indicating a 14.2%, 8.8%, and 13.8% decrease in flexural strength, respectively. The flexural strength of the 28-day samples, made with equal proportions of natural and recycled sand (without zeolite), was estimated at 4.73 MPa, and with an increase in the percentage of cement replacement with zeolite to 10%, 15%, and 25%, the flexural strength reached 4.74, 4.72, and 4.84 MPa, respectively, indicating a 0.8%, 9.2%, and 3.2% decrease in flexural strength, respectively (Figure 5b).

Additionally, a similar trend to Figure 5a was observed regarding the decrease in flexural strength of the 7-day and 28-day samples with constant zeolite values due to the increase in the replacement of recycled sand. It can be concluded that the presence of zeolite also has a reducing effect on the flexural strength of both 7-day and 28-day samples (Figure 5c). However, the presence of zeolite has increased the flexural strength of both 7-day and 28-day samples compared to samples without zeolite (Figure 5a), which can be attributed to the role of zeolite as a filler and pozzolan.

4. Conclusion

In this study, comprehensive studies and experiments were conducted on the performance and mechanical characteristics of mortars made with recycled sand and zeolite. Considering the priorities in sustainable development and the necessity of driving the construction industry towards these priorities in the country, the use of alternative materials for aggregates, as well as the recycling of construction and demolition wastes, and reducing the use of cement by incorporating cementitious materials such as zeolite, are essential. Below are the key findings of this study:

By replacing natural sand with recycled sand, the performance clearly follows a downward trend, even saturating the recycled sand exacerbates this trend. However, replacing cement with zeolite does not strictly follow an upward or downward trend; rather, it may increase up to a certain point and then decrease.

Increasing the replacement of natural sand with recycled sand and the substitution of cement with zeolite reduces the workability time.

Substituting natural sand with recycled sand reduces the bulk density of both fresh and hardened concrete due to the higher porosity of recycled sand compared to natural sand. However, increasing the replacement of cement with zeolite does not significantly affect the bulk density of fresh and hardened concrete since the specific gravity of cement and zeolite are similar.

As evident, increasing the replacement of natural sand with recycled sand increases the water absorption percentage of concrete, reaching up to a 2.4% increase with 100% replacement of natural sand with recycled sand. However, there is no consistent increasing or decreasing trend in water absorption percentage with increasing replacement of cement with zeolite.

The compressive strength of mortars containing recycled sand at both 7 and 28 days is lower than those made with natural sand. Furthermore, an increase in the percentage of replacement of natural sand with recycled sand results in a decrease in compressive strength. For instance, the compressive strength for the base sample at 28 days reached 28.18 MPa, while for the sample with 100% recycled sand, it decreased to 12.39 MPa. Additionally, although the replacement of cement with zeolite did not significantly alter the compressive strength at 7 days, an increase in strength was observed at 28 days. Specifically, the compressive strength of concrete with an equal ratio of natural and recycled sand was 26.99 MPa, and with 15% replacement of zeolite, it increased to 32.68 MPa. Despite meeting the acceptable limits according to the Iranian National Standard, the compressive strength of the samples was within acceptable ranges.

The flexural strength at 28 days was 5.54 MPa for the base sample and 8.13 MPa for the sample made with 100% recycled sand. Similarly to compressive strength, while the replacement of cement with zeolite did not significantly affect the flexural strength at 7 days, an increase in strength was observed at 28 days. Specifically, the flexural strength of concrete with an equal ratio of natural and recycled sand was 4.75 MPa, and with 15% replacement of zeolite, it increased to 5.25 MPa.

In conclusion, it can be argued that the use of recycled sand, due to its lower quality, leads to a reduction in the quality of mortar. However, this reduction in quality can be compensated for to a very acceptable extent by replacing it with zeolite. Furthermore, the utilization of zeolite assists in reducing cement consumption and environmental pollution. On the other hand, given the increasing demand for utilizing construction waste and preventing environmental degradation, replacing natural sand with recycled sand, considering its suitable qualitative and mechanical performance, can lead to the concept of green concrete.

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