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ORIGINAL ARTICLE

Influence of Internal Curing with Lightweight Pumice Fine Aggregate on the Mechanical Properties of Cement Mortars

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ABSTRACT – The cement mortar in the building encounters a problem of curing due to covering mortar under finishing materials such as tiles, stones, and marble. Internal curing is one of the methods for solving this problem. This investigation highlights the impact of internal curing with lightweight pumice fine aggregate on cement mortar's mechanical properties, such as compressive and tensile strengths, and performance, such as density. Thus, the internal cured water-to-cement ratio was studied, which varied from 0 to 21.5%, and the partial replacement of natural sand with lightweight pumice fine aggregate varied from 0% to 16.63%. The results showed the mechanical properties improved with the increased internal water-to-cement ratio. Increasing the internal cured water-to-cement ratio up to 21.52% improves the compressive, split tensile, and flexural strengths of cement mortar up to 77.3%, 56.42%, and 28.71%, respectively. In addition, the partial replacement of natural sand with lightweight pumice aggregate up to 10.9% enhances the compressive, split tensile, and flexural strengths of cement mortar up to 24.2%, 6.1%, and 28.7%, respectively, due to a reduction in drying and autogenous shrinkage.

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INTRODUCTION

The essential component for progressing strength in cement mortar is the continuity of its hydration. Hydration is a chemical reaction in which the major compounds in cement form a chemical bond with water molecules that convert the cement powder into a binding cement paste and gives its strength. Thus, the mortar and concrete cement must contain moisture by providing curing. Curing is the process that controls the rate and extent of losing moisture in the concrete during cement hydration. It is known that curing in concrete and mortar is essential at an early age, right after it has been placed, to provide time for the hydration to occur; another important role of curing in the concrete is reducing shrinkage, making it strong, increasing abrasion resistant, and increase the structures durability, as shown in Figure 1. Generally, curing is classified into two types, external curing, and internal curing, and each of these will be classified into other types such as; external curing is a traditional method based on curing applied from the surface of the concrete.

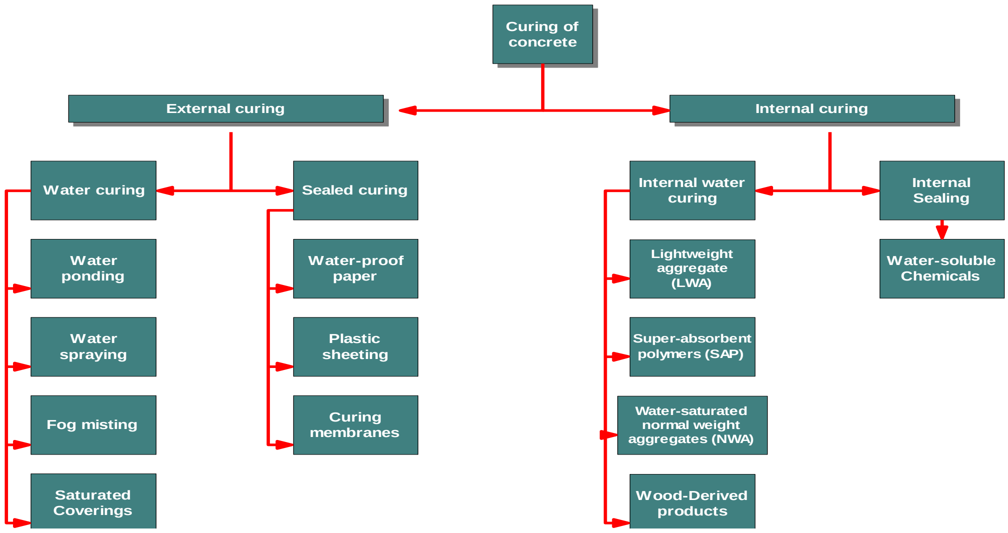

Figure 1. Classification of methods of curing concrete aimed to maintain moisture [1].

Since hydration of cement takes time days or weeks, curing must be undertaken for a reasonable period, which is continuous, typically for 3-7 days for cement mortar [2]; as long as this period increases, the cement paste gains more and more strength because hydration will continue at the surface of the concrete ASTM C109 [3]. Internal curing refers to the method that provides moisture from within the concrete as opposed to outside the concrete, and it is a new method that was discovered by the American concrete institute (ACI 318) and defined by them as "supplying water through a

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freshly placed cementitious mixture using reservoirs, via pre-wetted lightweight aggregates, that readily release water as needed for hydration or to replace moisture lost through evaporation or self-desiccation." It may achieve internal curing by using many agents such as (superabsorbent polymer, lightweight aggregate, and crushed brick waste); these agents create pores full of water inside the concrete, as shown in Figure 2 ACI 318 (2019) [4]. When the concrete sets these pores to contribute additional water to the concrete or the cement paste, the hydration will continue in the inner part of the concrete; more bonds will be produced between particles and increase concrete strength. The distribution of water in internal and external curing is shown in Figure 3. The most effective method for curing concrete depends on the materials, construction method, and the intended use of the hardened concrete.

Figure 2. Concrete with internal curing ACI 318 (2019) [4].

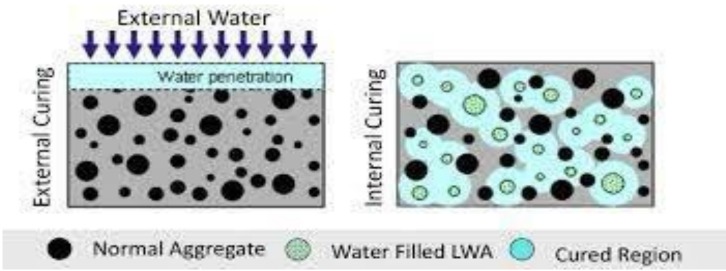

Figure 3. External curing vs. internal curing [1].

INTERNAL CURING METHOD OF CEMENT MORTAR

Internal curing provides something that most concrete needs and conventional curing cannot provide additional internal water to prevent early-age shrinkage and increases the hydration of cementitious materials throughout the concrete. Internal curing agents are incorporated into the concrete as an admixture. These agents are (lightweight aggregate, super absorbent polymer, and crushed clay brick). They are used as internal agents because of their high porosity and low density and can provide additional water to the cement [5, 6].

BENEFITS OF USING INTERNAL CURING IN CEMENT MORTAR OR CONCRETE

Internal curing provides some advantages in concrete and cement mortar, such as:

a) Internally cured mortar mixtures using saturated lightweight aggregate could significantly reduce or eliminate plastic shrinkage cracking [7].

b) Improved cement hydration due to internal curing is one benefit of lightweight concrete in structures [8].

c) Using Prewetted lightweight aggregate as internal curing in cement mortar contribute to an enhancement in hydration which may translate into strength gain [9].

SIGNIFICANCE OF THE RESEARCH

A goal of using internal curing in cement mortar mixtures is to reduce the strain that will influence the potential of mortar to crack; using lightweight pumice fine aggregate as an agent for internal curing helps the mortar to reduce shrinkage and to achieve a lightweight mortar for buildings. Besides many other properties of the mortar changes, especially it’s compressive and tensile strengths, this method is also useful for places with insufficient water for external curing.

LITERATURE REVIEW

Internal curing has been the subject of many laboratory investigations over the last two decades, and many types of research have been written about internal curing using different agents. Still, few of them were about using lightweight aggregate for the internal curing of mortars. Besides this, the following researches demonstrate the effect of using different agents for internal curing in cement mortar and concrete.

Effect of internal curing agents on the properties of concrete

Feng Chen [10] investigated the effects of coarse aggregate types (recycled brick aggregate concrete, recycled concrete aggregate), the replacement ratio of recycled coarse aggregate to the total amount of coarse aggregate ranging from 0% to 100%, and four curing ages, including 7, 14, 21 and 28 days. The result showed that the replacement ratio of recycled brick aggregate increases from 0% to 100%, the compressive strength at 7 and 14 days of curing decreases up to 50.5%, whereas it improves up to 32.5% for 21 and 28 days of curing due to the positive Effect of using recycled aggregate concrete as internal curing material, as shown in Figure 4.

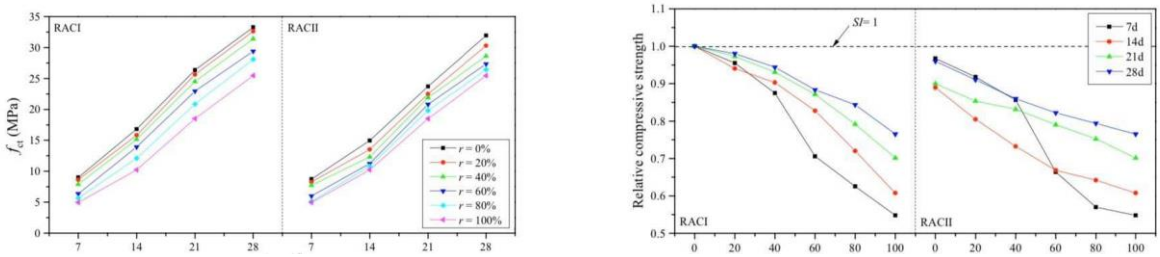

Figure 4. Results of RACI and RACII Feng Chen (2019) [10].

El-Dieb [11] investigated the influence of water-soluble polymeric glycol as a self-curing agent. In addition, water retention and hydration of concrete containing self-curing agents are investigated and compared to conventional concrete. The main parameters were water-to-cement ratio and cement content divided into eight mixed. The self-curing agent used in the study was water-soluble polymeric glycol with a constant rate (0.02%) for all self-curing concrete mixes. The weight loss, internal relative humidity, non-evaporable water at different ages and absorption, permeability voids, and water sorptivity were measured. The results show that the performance of the self-curing agent is affected by the mix proportions, mainly the cement content and water-to-cement ratio, and water retention for the concrete mixes incorporating the self-curing agent is higher than conventional concrete mixes, with weight loss via time. Moreover, water transport through self-curing concrete is lower than air-cured conventional concrete, shown in Figure 5.

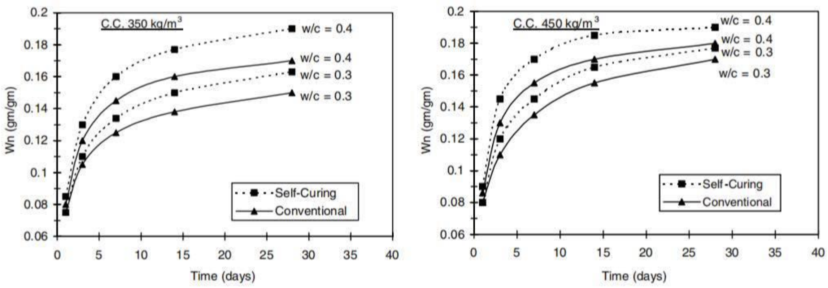

Figure 5. Non-evaporable water versus time for self-curing and conventional mixes [11].

Effect of internal curing agents on the properties of cement mortars

Bentz [12] studied the Effect of different curing agents on the compressive strength, modulus of elasticity, and shear slant bond using three different materials for internal curing such as lightweight aggregate, superabsorbent polymer, superabsorbent polymer-coated sand, as shown in Figure 6. The result showed that the mortars using lightweight aggregate to provide internal curing exhibited the highest compressive strength and the greatest reductions in autogenous deformation and slightly reduced ultimate drying shrinkage.

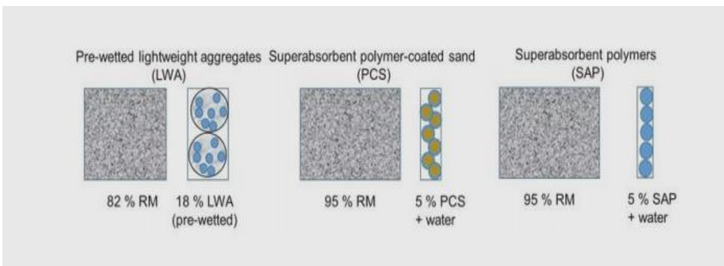

Figure 6. Concrete with repaired materials [12].

Shakir [13] investigated the Effect of using crushed brick waste (CBW) in cement mortar mixtures prepared by substituting natural sand with crushed brick waste in different percentages (5, 10, 15,20 and, 25%) on the properties of cement mortar such as fresh density, hardened density, compressive strength, water absorption, and modulus of rupture. The results showed that the compressive strength and modulus of rupture were decreased with the addition of CBW, whereas they were higher for mortars cured in air conditions than those cured in water and partially in water curing which improved by using internal curing agent CBW, as shown in Figure 7. Moreover, three curing regimes were adopted in this study: water curing by immersing specimens in water for 28days, partially water curing by immersing specimens in water for three days and leaving them in the laboratory for 24, and air curing in the laboratory for 28 days.

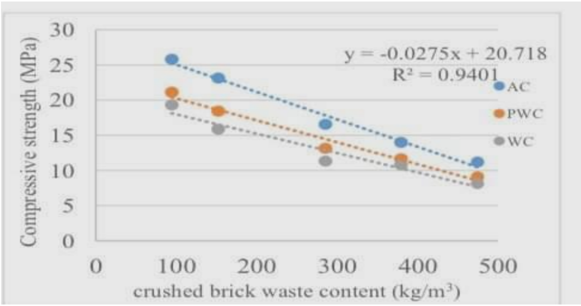

Figure 7. Compressive strength after using CBW [13].

Esteves [14] examined the Effect of curing conditions such as curing temperature and relative humidity varied from 20 to 40 °C and 30% to 95%, respectively, on the mechanical properties of mortars containing superabsorbent polymers (SAP). The results showed that SAP examples cured at a higher temperature, 40°C, exhibit lower strength than when cured at low humidity (30% R.H.), as shown in Figure 8.

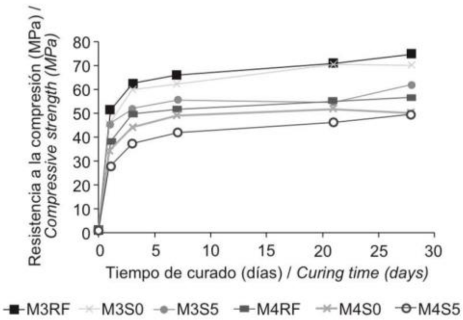

Figure 8. Compressive strength versus time for mortars cured at 20℃ and RH>95% [14].

To sum up, the main crucial issue for cement mortar is the reduction in flexural strength while used under tiles or for bonding without curing, or it could not be cured due to covering by tiles or other finishing material. Thus using lightweight pumice fine aggregate as an internal curing agent might increase the bond strength and enhance the flexural strength of internal cured cement mortar.

EXPERIMENTAL PROGRAMME

Fine aggregate

Standard sand is used in the study, which shall meet all the requirements concerning grading and the absence of undesirable air en-training characteristics ASTM C778 (2017) [15].

The coarse pumice aggregate was crushed with a crushing machine to make the lightweight pumice fine aggregate. Thus, the product from the crusher passed through a sieve of 4.75 mm to be sure for adopting the product for being fine aggregate, as shown in Figure 9.

(a) Lightweight pumice coarse aggregate

(b) Crushing lightweight pumice coarse aggregate to fine aggregate

(c) Sieving lightweight pumice fine aggregate

Figure 9. Preparation of lightweight pumice fine aggregate.

Portland Cement

The type of cement used in this study was Tasluja Ordinary Portland Cement from TCC Company. The physical properties of the cement are summarized in Table 1. These properties have complied with ASTM C150 [16].

Table 1. Physical properties of the Tasluja cement.

No	Physical test	Result	ASTM limit
1.	Average cube 2 inches' compressive strength, (N/mm^2) 7-days	23.6	19 MPa, lower limit
2.	Setting time Initial, minutes Final, minutes	 125 240	 Not less than 45 min. Not more than 375 min.
3.	Normal consistency, %	33	N/A
4.	Specific gravity	3.1	N/A

METHODOLOGY

The objectives for conducting this investigation are to determine the influence of different partial replacements of lightweight pumice fine aggregate (LWS) with natural sand, which varying from 0% to 16.63%, and different percentages of internal cured water to cement ratio, which varied between 0% and 21.5% on the compressive and tensile strengths. The details of each mix are explained in Table 2.

Table 2. Samples' notations.

Code	Mix proportion (W: C:S)*	Partial replacement of lightweight pumice fine aggregate with natural sand	Internal cured water to cement ratio (ICW/C)**
A0	0.485:1:2.75	0	0
A1	0.485:1:2.75	5.45	
A2	0.485:1:2.75	10.90	
A3	0.485:1:2.75	16.63	
B0	0.60:1:2.75	0	0.115
B1	0.60:1:2.75	5.45	
B2	0.60:1:2.75	10.90	
B3	0.60:1:2.75	16.63	
C0	0.70:1:2.75	0	0.215
C1	0.70:1:2.75	5.45	
C2	0.70:1:2.75	10.90	
C3	0.70:1:2.75	16.63	

*:W:C:S is the water-to-cement-to-sand ratio
**: ICW/C is the internal cured water-to-cement ratio

RESULTS AND DISCUSSIONS

Influence of Internal Curing Water on the Mechanical Properties of Cement Mortar

Internal cured water by lightweight pumice fine aggregate affects all mechanical properties and performance of cement mortar. The following sections describe their Effect on the compressive, split tensile, and flexural strengths of cement mortar and their density.

Compressive Strength

The 2-inches cube compressive strength of cement mortar was determined based on ASTM C109 [3]. One factor affecting the result of this test is the water-to-cement ratio. The results show that the compressive strength improves up to 77.3% due to an excess internal water-to-cement ratio of up to 21.5% even though high partial replacement of natural sand with lightweight pumice fine aggregate up to 16.63%, as shown in Figure 10. According to ACI 308-213 [9], prewetted lightweight aggregate improves the hydration in cement mortar, and this improvement may translate into strength achievement. However, the samples are not cured, just left in the zip bag to find the influence of internal water on these properties. Thus, the wet curing method cannot contact water with cement inside the mortar due to the filling of capillary pores outside or a thin layer of cement mortar, such as in UHPFRC. The latter is still not cured inside of the cubes due to the same reason, which is like a dry ball inside this kind of concrete.

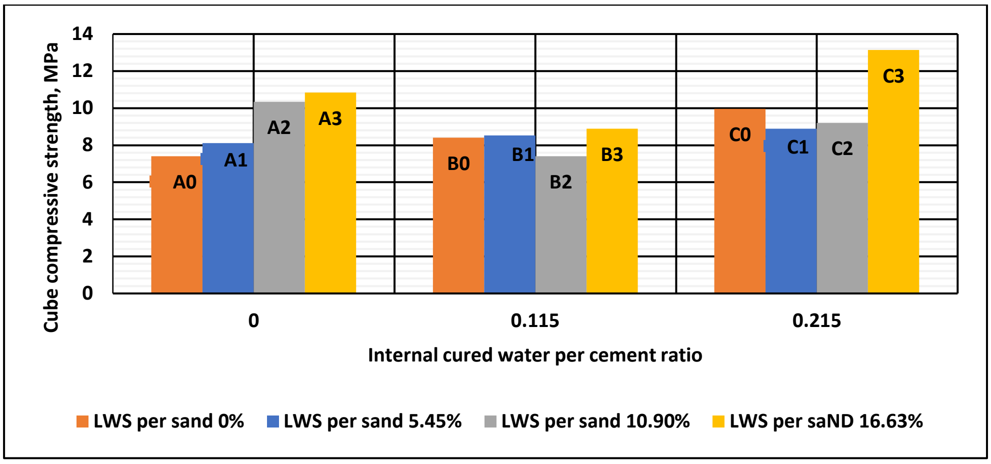

Figure 10. Cube compressive strength of mortar versus Internal cured water per cement ratio.

Split Tensile Strength

This test method consists of applying a diametric compressive force along the length of a cylindrical mortar specimen at a rate within a prescribed range until failure occurs. According to ASTM C496 [17], plywood bearing strips are used so that the load is applied uniformly along the length of the cylinder, as shown in Figure 11. This loading induces tensile stresses on the plane containing the applied load and relatively high compressive stresses immediately around the applied load.

Figure 11. Specimen prepared to split tensile test.

Autogenous shrinkage inside cement mortar is produced due to it not contacting water with cement inside it. Thus, the internal cured water encourages the growth of cement mortar strength [9], as shown in Figure 12. It can be seen from the figure that the split tensile strength increased to 56.42% due to an improved internal cured water-to-cement ratio of up to 21.5%.

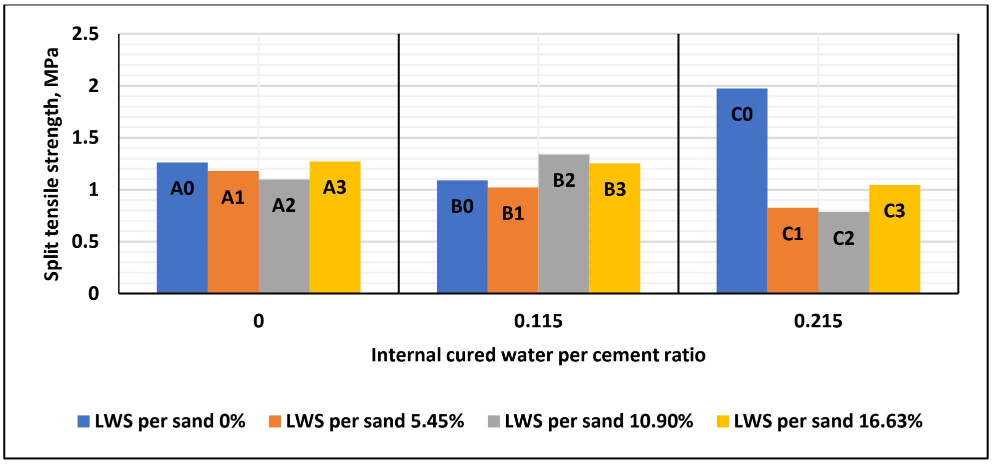

Figure 12. Split tensile strength of mortar versus Internal cured water per cement ratio.

Flexural Strength

The flexural strength of cement mortar is one of the mechanical properties affected by curing, such as cement mortar beneath tiles. Thus, internal cured water affects the flexural strength of cement mortar by producing cavities, partially replacing natural sand with lightweight pumice fine aggregate, and encouraging the filling of pores inside cement mortar with internal cured water. The three prisms were tested according to ASTM C348 [18], as shown in Figure 13.

Figure 13. Prism specimen prepared to be tested.

The effects of the internal cured water-to-cement ratio on the flexural strength are shown in Figure 14. As a result, the flexural strength of cement mortar was enhanced up to 43.60% due to increasing internal cured water to cement ratio up to 11.5%, whereas this improvement reduced up to 28.71% due to partial replacement of natural sand with lightweight pumice fine aggregate in the mortar around 16.63%.

Density

The density of cement mortar was found based on ASTM C642 [19], which is useful for reducing the dead load on building in general. The increase in the internal cured water-to-cement ratio affects the cement mortar's compressive strength-to-density ratio, as shown in Figure 15. It can be seen from the figure that the strength-to-density ratio improves up to 31.1% due to increasing the internal cured water-to-cement ratio up to 21.5%.

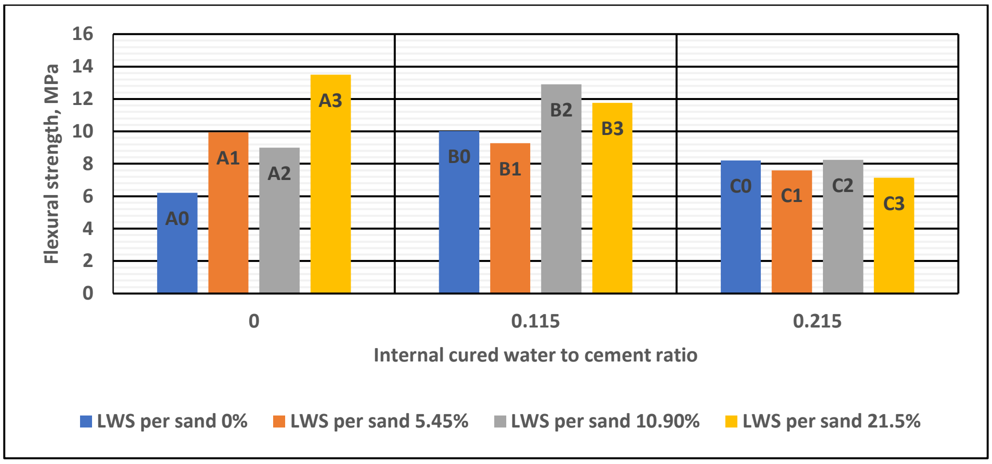

Figure 14. Flexural strength of mortar versus Internal cured water per cement ratio.

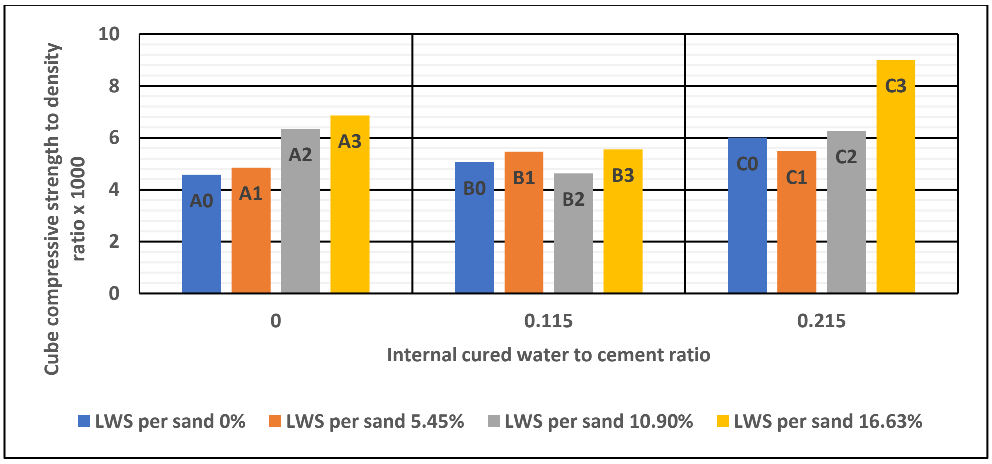

Figure 15. Cube compressive strength to density ratio versus Internal cured water per cement ratio.

Influence of the Partial Replacement of Lightweight Pumice Fine Aggregate with Sand on the Mechanical Properties of Cement Mortar

The lightweight pumice fine aggregate is softer than natural sand, and it could hold water inside of mortar for 28 days based on the amount inside of cement mortar. Thus, the partial replacement of natural sand with lightweight pumice fine aggregate affects the compressive, tensile strengths and the density of mortar.

Compressive Strength

The effect of the partial replacement of natural sand with lightweight pumice fine aggregate is shown in Figure 16. The figure shows the improvement of the compressive strength of mortar up to 77.3% due to the partial replacement of sand with lightweight pumice fine aggregate around 16.63%, which held more water for internal curing.

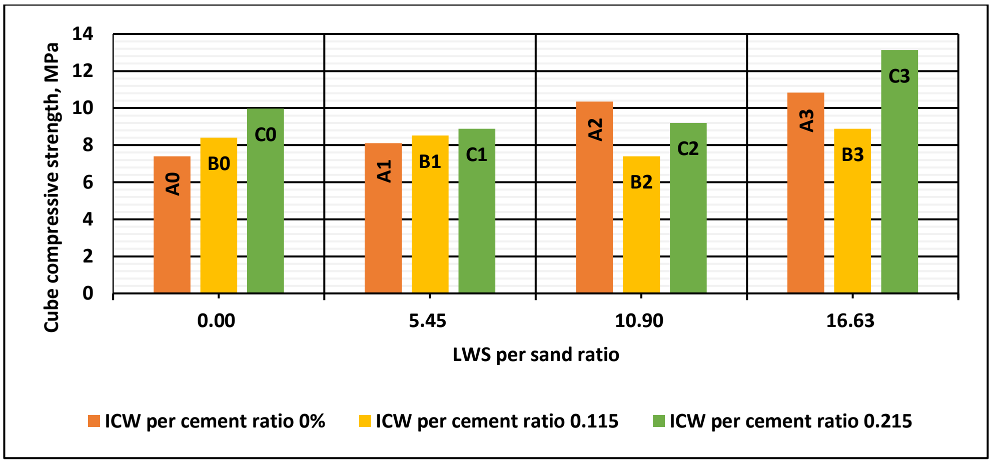

Figure 16. Cube compressive strength versus lightweight pumice sand to total sand ratio.

Split Tensile Strength

The influence of the partial replacement of natural sand with lightweight pumice fine aggregate on the split tensile strength of mortar is shown in Figure 17. The figure shows a slight enhancement of split tensile strength due to softening of lightweight pumice fine aggregate.

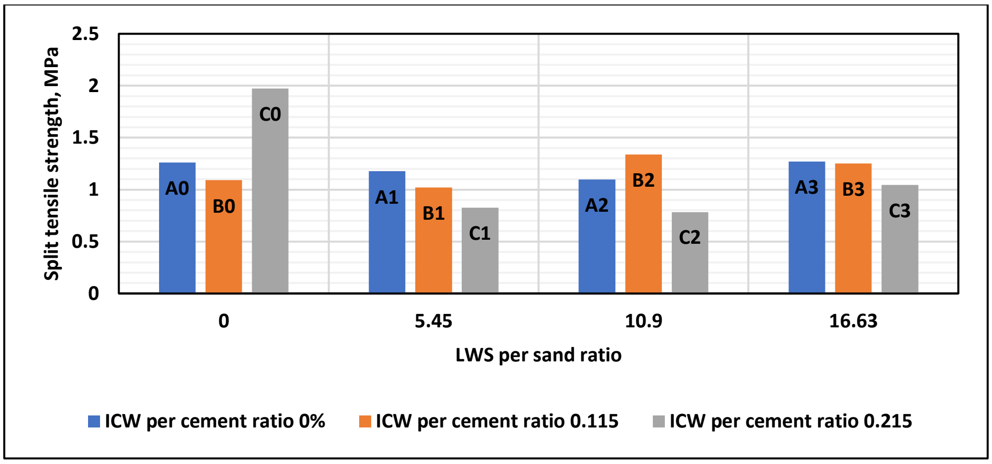

Figure 17. Split tensile strength versus lightweight pumice sand to total sand ratio.

Flexural Strength

The flexural strength of cement mortar influences by the partial replacement of natural sand with lightweight pumice fine aggregate, as shown in Figure 18. It can be seen from the figure that the flexural strength improves up to 28.7% due to replacing 10.9% of natural sand with lightweight sand. This improvement comes from a reduction in dry shrinkage in cement mortar.

Density

The density of cement mortar affects by the partial replacement of natural sand with lightweight pumice aggregate, as shown in Figure 19. It can be seen from the figure that the cube compressive strength-to-density ratio improves up to 95.6% due to adding lightweight fine sand instead of natural sand and the capability of lightweight pumice fine aggregate to contain water up to 21.5% concerning cement mass. Thus, it is encouraged that the designer uses lightweight sand to reduce the dead load of the building without a reduction in strength.

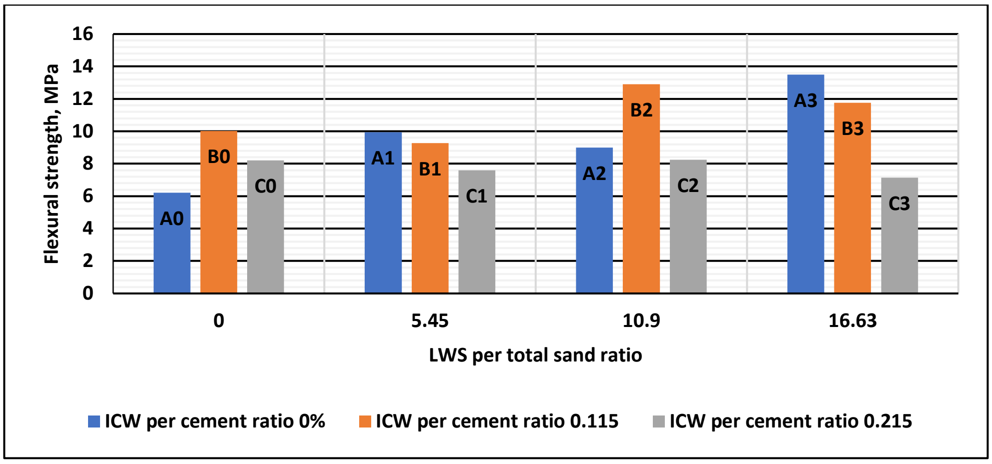

Figure 18. Flexural strength versus lightweight pumice sand to total sand ratio.

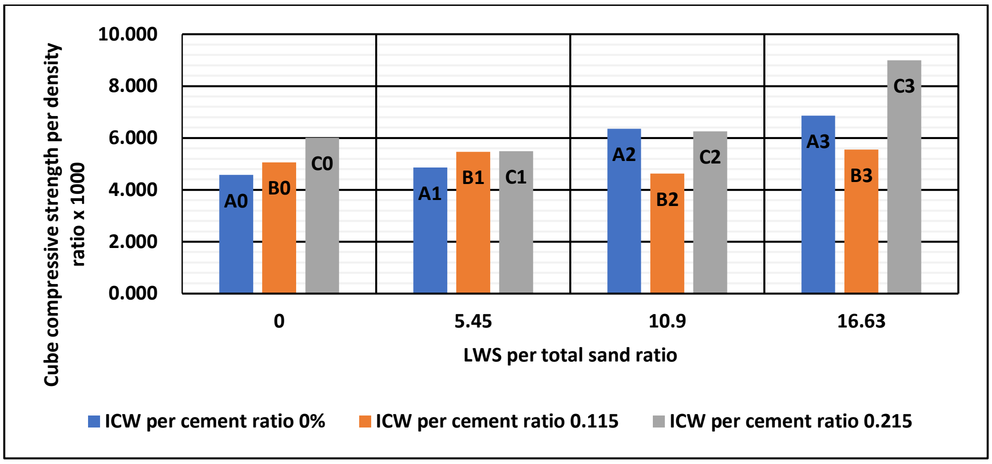

Figure 19. Cube compressive strength per density ratio versus lightweight pumice sand to total sand ratio.

CONCLUSIONS

The following conclusions could be drawn from the results of this research on the influence of internal cured water and the partial replacement of natural sand with lightweight pumice fine aggregate on the mechanical and performance of cement mortars:

a) Increasing the internal cured water-to-cement ratio up to 21.52% improves the compressive, split tensile, and flexural strengths of cement mortar up to 77.3%, 56.42%, and 28.71%, respectively.

b) The partial replacement of natural sand with lightweight pumice aggregate up to 10.9% enhances the compressive, split tensile, and flexural strengths of cement mortar up to 24.2%, 6.1%, and 28.7%, respectively, due to a reduction in drying and autogenous shrinkage.

c) The compressive strength-to-density ratio improves up to 95.6% due to adding 16.63% of the lightweight sand in the cement mortar. Consequently, it may reduce the mass of the building.

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