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Influence of Pulverized Lightweight Pumice Fine Aggregate on the Cement Mortar's Dry Shrinkage

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ABSTRACT

The use of lightweight aggregates in cement concrete manufacturing solves the issue of drying shrinkage over the concrete's life span; nevertheless, the use of artificial lightweight sand may increase this issue in the cement mortar. This research looks at how using lighter sand affects the non-mechanical qualities of cement mortar, namely the dry shrinkage property. It was prepared lightweight sand by pulverising pumice stone, screening it through a 1.18 mm sieve, and combining it with regular natural sand in varied amounts. It was tested various replacement percentages for lightweight sand by weight, such as 10%, 12%, 14%, 16%, and 18%, while keeping a single control sample without any lightweight pulverized pumice sand. As the proportion of pulverized pumice lightweight fine aggregate increases, the dry shrinkage of cement mortars containing pulverised lightweight pumice fine aggregate enhanced up to 161%, which has a negative impact on the durability of the cement mortar despite improved compressive and split tensile strengths of cement mortar. Moreover, the value of the brittleness index of the cement mortar reduced due to improvement of the split tensile strength. However, the bulk dry density of the cement mortar reduces up to 13.2%, which supports the reduction of the dead load in the high-rise buildings.

Keywords: Cement mortar, Drying shrinkage, Pulverized lightweight pumice sand, Pumice stone.

1. INTRODUCTION

Concrete shrinkage is the decrease in volume caused by the loss of moisture or other physical and chemical changes that occur during curing and drying. This loss in volume may cause fissures, compromising the concrete's structural integrity and long-term sustainability. The shrinking of concrete goes through three separate phases. During the first few hours following concrete installation, fast evaporation of water from the surface due to

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environmental conditions such as high temperature, low humidity, and wind produces plastic shrinkage, resulting in surface fractures that typically occur perpendicular to the wind's direction, as illustrated in **Fig. 1 (Sayahi, 2019)**.

Figure 1. Plastic shrinkage on the concrete surface **(Sayahi, 2019)**.

Another type of drying shrinkage in concrete happens after the material has set and starts to lose moisture to the environment. It occurs owing to the evaporation of water through the capillary pores inside the concrete that has been hardened, and this sort of shrinkage may produce large internal strains, resulting in fractures throughout the concrete mass, as shown in **Fig. 2 (Safiuddin et al., 2018)**.

Figure 2. Dry shrinkage in the cemented concrete surface **(Safiuddin et al., 2018)**.

Thermal shrinkage is the third form of shrinkage in concrete. It occurs as the temperature fluctuates throughout the curing process, and is particularly noticeable in the first few days to weeks. It develops to temperature fluctuations inside the concrete mass, as shown in **Fig. 3 (Al-Gburi, 2014)**.

Figure 3. Thermal shrinkage of reinforced concrete walls **(Al-Gburi, 2014)**.

The shrinkage in cement mortar refers to the reduction in volume that transpires throughout the setting and hardening processes, largely owing to water loss. May cause cracking and have a substantial impact on the mortar's longevity and performance, as shown in **Fig. 4 (Patel, 2017)**.
Shrinkage in cement mortar may have several negative consequences, including structural and quality issues. Furthermore, drying shrinkage cracks form over time as the mortar loses moisture and contracts, resulting in deeper and more widespread breaking; hence, both are classified as surface cracks. During the hydration process, chemical reactions cause autogenous shrinkage fractures, which lead to interior micro-cracks, particularly in high-strength mortars with low water-cement ratios.

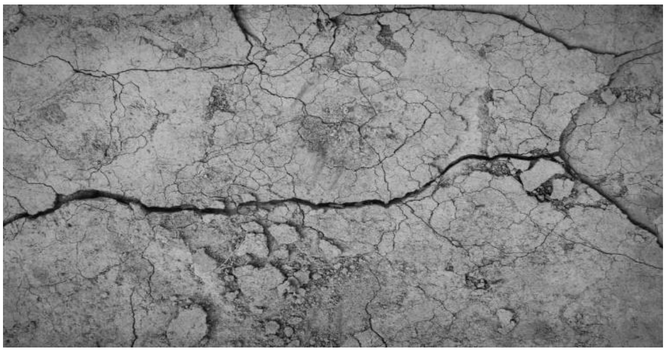

Figure 4. Shrinkage of cement mortar **(Patel, 2017)**.

Various factors impact cement mortar shrinkage, altering both its amount and pace of contraction. It's important to understand that raising the aggregate volume of the cement paste minimizes shrinkage. However, adding additional moisture within the mixture via the internal curing technique improves the hydration of concrete, such as lightweight aggregates such as pumice, which is pre-wetted to ensure it contains sufficient water to release during the curing process, where the low water-cement ratio can lead to incomplete hydration and shrinkage cracking.
Internal curing with lightweight pumice aggregate involves the following steps: Pre-wetting the aggregate, mixing, hydration, water release, and ongoing curing, as shown in **Fig. 5**. The progressive release of water from the lightweight aggregates helps maintain a greater internal relative humidity, lessening the effects of self-desiccation and reducing the possibility of shrinkage cracking **(Hamzah et al., 2022)**.

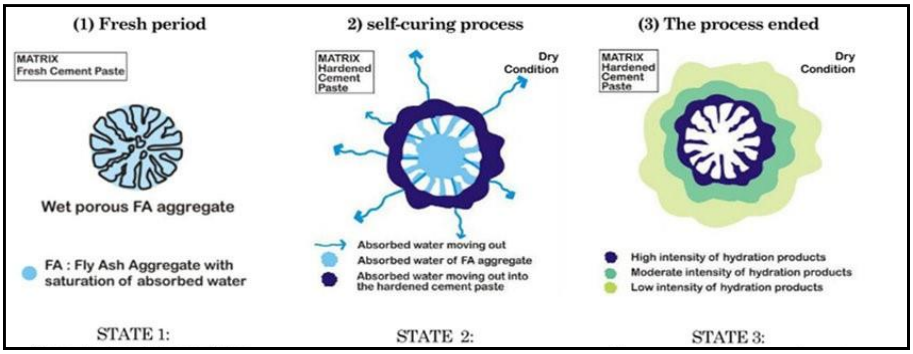

Figure 5. Steps for internal curing concrete **(Hamzah et al., 2022)**.

Construction experts may utilize a pumice stone to manufacture lightweight concrete, which merely makes the concrete lighter but also improves its insulating characteristics, as illustrated in **Fig. 6**.

Figure 6. Pumice aggregate has been pulverised.

2. THE SIGNIFICANCE OF THE STUDY

The crucial issue in the cement mortar is the drying shrinkage from the difficulty of curing while used the cement mortar in rendering, under tiles and for repairing purpose. Thus, internal curing is the proper way to reduce this shrinkage. The most important material for this purpose is the pumice aggregate which has a good hardness, thus it may improve the mechanical properties on the cement mortar as result. Thus, it could be a challenge to use it in the cement mortar.

3. DRYING SHRINKAGE IN CEMENT MORTARS

Drying shrinkage in cement mortar is a crucial phenomenon with a substantial influence on the performance and durability of cement mortars **(Ghanem et al., 2024)**. Several variables impact the occurrence, including the size of the pores solution's chemical composition and the water-to-cement ratio (w/c). As the w/c falls, the ionic concentration rises, which leads to a reduction in double-layer repulsion and consequent flocculation of tiny particles in the C-S-H gel, eventually causing macroscopic shrinkage **(Nawa, 2018)**.
Awareness of drying shrinkage requires an understanding of how pre-soaked lightweight aggregate affects the volume stability of mortar and concrete mixes. The weight of evaporation water to the initial weight of unhydrated cement in the sample gives insights into the effect of the water-to-cement ratio on drying shrinkage **(Ardeshirilaijimi et al., 2017)**. The water-to-binder ratio (w/b) is an important material attribute that affects autogenous shrinkage (AGS), both of which contribute to drying shrinkage. A low w/b ratio results in a high AGS, with cement composition and the addition of supplemental cementitious materials (SCMs) also influencing these characteristics. Notably, the addition of fly ash (FA) to concrete was shown to minimize AGS **(Ghanem et al., 2024)**. In addition, the inclusion of the fly ash and ground granulated blast furnace slag have a positive impact on the drying shrinkage of the cement mortar. Besides, the drying shrinkage decreased significantly with the increase in the fly ash and ground granulated blast furnace slag content **(Al-sairafi et al., 2018)**. While the drying shrinkage influences with grain size of sand, and filler content and it improves due to increasing the size of sand particles **(Malathy and Subramanian, 2007)**.

Both humidity and temperature are among the factors that might influence drying shrinkage. The cause of drying shrinkage in hardened cement paste is attributed to hydration pressure, as noted by **(Ye and Radlinska, 2016)**.

3.1 Mechanisms of Drying Shrinkage

Drying shrinkage in cement mortar takes place by two primary processes: capillary stress theory and autogenous shrinkage. The capillary stress concept is linked to the drying process, in which the evaporation of water from the cement mortar causes capillary tension inside the material. This stress is caused by the surface tension of water and the porous nature of the cement mortar. Autogenous shrinkage is connected with the self-desiccation of the material during the early stages of cement hydration, resulting in internal pore structure formation and capillary internal strains **(Ghanem et al., 2024)**.

3.1.1 Capillary Stress Theory

The proposed theory emphasizes the relevance of capillary pressure and disjoining pressure at various levels of saturation, showing the intricate interaction of these forces in shrinkage issues. According to Nawa **(Nawa, 2018)**, as the cement paste dries, disjoining pressure removes absorbed water from the pores, and capillary tensions generate a meniscus that strains the C-S-H skeleton, causing the cemented paste to shrink. Furthermore, the theory addresses the hysteresis of sorption isotherm associated with absorbate condensation and evaporation in mesoporous materials like cement paste, supplying insights into the pore size distribution and pore array structure **(Ye and Radlinska, 2016)**.

3.1.2 Autogenous Shrinkage

Autogenous shrinkage is the phenomena involved in premature micro cracking of the cement mortar **(Bouasker et al., 2018)**. The factors have an impact on the amount of this shrinkage are the temperature which reduces the age of cracking when the temperature increases **(Bouasker et al., 2018)**. In addition, using the internal curing with lightweight aggregate exhibit the greatest reductions in autogenous shrinkage in repair cement mortar **(Bentz et al., 2015)**. However, the autogenous shrinkage might increase due to inclusion of limestone powder **(Itim et al., 2011)**. Moreover, in the early age, the autogenous shrinkage of ultra-high-strength mortar can be effectively decreased by including expansive additive, such as silica-fume pre-mixture cement which obtain a non-shrinking state with adding 7% of the binding materials in the mixture**(Zhang et al., 2018)**. However, the presence of pozzolanic materials in the cement mortar might increase the autogenous shrinkage due to high water absorption of these material in the mixture of the cement mortar **(Itim et al., 2011; Malathy and Subramanian, 2007)**.

Therefore, the autogenous shrinkage is a crucial part of drying shrinkage in cement mortar since it contributes significantly to early cracking. It is closely connected to chemical shrinkage, which is the driving factor behind self-desiccation and drying shrinkage.

The chemical shrinkage is the phenomenon appears while the cement react with water, the volume of reaction products is similar than the sum of the reactants, which reaches 25% by

volume of the reacted water. This type of shrinkage is learly related to the degree of hydration of the cement **(Justnes et al., 1999)**.
The values of chemical and autogenous shrinkages are identical in the early phases of the hydration process of cement, yet they diverge at the hardened stage**(Ghanem et al., 2024)**. Besides, the chemical shrinkage is the reason behind early age cracking, which is a common problem for concrete with low water-to-cement ratio less than 0.35 **(Kheir et al., 2021)**. Thus, the chemical shrinkage increased with increasing water content because cement pastes with higher water to cement ratio have higher degree of hydration and more water exist in the mixture for hydration of the cement grains **(Gao et al., 2020)**. Furthermore, the type of cement plays a role in controlling the chemical and autogenous shrinkages of cementitious system **(Ghanem et al., 2024)**, the chemical shrinkage of the cement paste with Portland cement type III had slightly higher rates than Portland cement type I **(Kheir et al., 2021)**. Besides, the increase of chemical shrinkage and hydration rate depends on the cement type. While the presence of limestone filler causes an accelation of the chemical shrinkage and the hydration process since the early age of the cement mixture **(Bouasker et al., 2008)**.
The water-to-binder ratio (w/b) has a substantial impact on CS, with lower amounts resulting in increased CS and autogenous shrinking. Furthermore, the composition of cement and the use of supplemental cementitious materials (SCMs) such as fly ash (FA) affect both shrinkage characteristics. The incorporation of FA decreases CS and autogenous shrinkage **(Ghanem et al., 2024)**.
Shrinkage diminution admixtures (SRAs), lightweight aggregates (LWAs), and expansive types of cement are among the strategies used to reduce concrete's susceptibility to shrinkage cracking. SRAs have been demonstrated to minimize drying shrinkage in concrete by up to 50%, while LWAs may offer internal curing of concrete, decreasing the effects of self-desiccation and lowering autogenous shrinkage **(Ardeshirilaijimi et al., 2017)**.

3.2 Mitigation Strategies

Combating the effects of drying shrinkage in cement mortar necessitates the deliberate application of shrinkage-reducing admixtures (SRAs) along with suitable curing procedures **(Ardeshirilaijimi et al., 2017)**.

3.2.1 Use of Shrinkage-Reducing Admixtures

Shrinkage-reduction admixtures (SRAs) serve an important function in limiting drying shrinkage in cement mortar. These admixtures are intended to decrease the surface tension of water in concrete, resulting in a lesser amount of capillary strains during the drying process **(Ardeshirilaijimi et al., 2017)**.

3.2.2 Curing Techniques

Curing tactics are critical in reducing drying shrinkage in cement mortars. Several approaches have been investigated to overcome that issue, such as implementing lightweight aggregate for internal curing, heat curing, and steam curing. Ascensão et al. **(Ascensao et al., 2019)** point out the benefits of heat curing in decreasing shrinkage in alkali-activated concretes. The investigation reveals that heat curing, alongside room temperature pretreatment, could substantially boost volumetric stability in cementitious materials. Additionally, it shows that curing in a steam-saturated atmosphere has a substantial effect on the entire drying shrinkage of inorganic polymer mortars.

3.3 Effect of Aggregate on Drying Shrinkage

Different types and quantities of aggregate have significant effects on the drying shrinkage of cement mortar. With a fixed ratio of water to cement and cement type, the shrinkage of cement mortar comes in greatly as its fine aggregate content goes up **(West et al., 2010)**. This is related to the aggregate's contraction resilience; further aggregate content implies lower cement paste content, which is prone to shrinking. The impact of aggregate size and volume fraction on shrinkage-induced micro-cracking and permeability of cement mortar was researched, and they noticed that increasing aggregate diameter while lowering volume fraction drastically improves permeability **(Grassl et al., 2009; Hachim and Fawzi, 2012; Al-Awadi and Fawzi, 2017; Selman and Abbas, 2022; Jassem and Fawzi, 2024)**.

3.4 Impact of Temperature and Humidity

The contribution of temperature and humidity on drying shrinkage in cement mortar is a significant consideration in building applications. Likewise, Ardeshirilajimi emphasizes the measurement of capillary porosity and non-evaporable water in the cement mortar altered with pre-soaked lightweight aggregate on volume stability, and then lowering drying shrinkage as a direct result **(Ardeshirilaijimi et al., 2017)**.

4. EXPERIMENTAL PROGRAM

This study investigates the influence of pulverized lightweight pumice sand on the dry shrinkage of cement mortars, as well as its effects on compressive and tensile strengths. **Table 1** displays the two stages of this investigation, which take place at 7 and 28 days. All the mixes in this investigation were prepared using a consistent amount of water, with a cement-to-sand proportion of 1:2.75 and water-to-cement was 0.88. The combinations A1, A2, A3, A4, and A5 included varying amounts of pulverized lightweight pumice sand, namely 10%, 12%, 14%, 16%, and 18%, respectively.

4.1 Preparation of the Specimens

The samples of cement mortars were prepared using ordinary Portland cement and standard sand in a ratio of 1:2.75, which should meet ASTM requirements **(ASTM C150/C150M-22, 2022; ASTM C330/C330M-23, 2023)**, and the ratio of water to cement was determined using a flow table test, while the consistency of cement mortar should have been wet, so the required percentage of flow was between 105%-110%, which was 1:0.88.Six cubic molds with side lengths of 50 mm, six steel cylinders with diameters of 50 mm and heights of 100 mm, and three prisms for measuring drying shrinkage in cement mortar with cross section dimensions of 25 × 25 mm and length of 285 mm **(ASTM C157/C157M-08, 2008; ASTM C496/C496M-11, 2011)**.

Table 1. Experimental program for incorporating lightweight sand into the cement mortar.

Code	Lightweight sand/Total sand, %	Number of samples				
		Prism for shrinkage, 25x25x285 mm	Cubes for compressive strength, 50x50x50 mm		Cylinder for split tensile strength, 50 mm in diameter by 100 mm in height	
Age, days	-	7 and 28	7	28	7	28
A0	0	3	3	3	3	3
A1	10	3	3	3	3	3
A2	12	3	3	3	3	3
A3	14	3	3	3	3	3
A4	16	3	3	3	3	3
A5	18	3	3	3	3	3

The molds were cleaned and lubricated with oil before adding the cement and water to the stand mechanical mixer in the proportions specified in the design, as illustrated in **Fig. 7 (ASTM C305-20, 2020)**. The aggregate was then added to the mixer and mixed for 5 minutes to produce a consistent consistency. Following the flow table test, the cement mortar mixture was cast into the conical cone in two layers, with each layer compacted 16 times with the conventional tamper, as illustrated in **Fig. 8**. Moreover, the cylinder was cast in two layers and crushed by a vibrating table. The cement mortar cubes were cast in two layers and crushed for 20 seconds using a vibrating table. After 24 hours, the molds were removed, and the samples were placed in the drying room, with the exception of the primes of drying shrinkage, which were soaked in saturated lime water for 24 hours before being removed and preserved in the drying chamber, as shown in **Fig. 9 (Karim, 2022)**.

4.2 Preparing Pulverized Pumice Sand

Fig. 10 shows the results of crushing the pumice aggregate stone using a grinding mill equipment. The pulverized pumice fine aggregate must next pass through a sieve with a size of 1.18 mm **(Karim, 2022)**. Afterwards, the pulverized pumice sand was combined with the necessary water in a magnetic mixer set to 400 rpm for three minutes. This was done to achieve a uniform consistency and to avoid any clogging that could occur during the cement mortar preparation process, as shown in **Fig. 11 (ASTM C192/C192M-18, 2018)**.

Figure 7. Mixing with a stand mixer.

Figure 8. Flow table test for cement mortar of control sample.

Figure 9. Prism samples of cement mortar for drying shrinkage testing.

Figure 10. Grinding equipment used to pulverise pumice aggregate.

Figure 11. Magnetic mixer.

4.3 Tests of the Mechanical and Some of Non-Mechanical Properties of Cement Mortar

4.3.1 Compressive Strength

The compressive strength test is a crucial examination used to ascertain the capacity of cement mortar to endure axial compression forces. This test is essential for evaluating the caliber and efficiency of cement mortar used in building. As per ASTM C109/C109M, a total of 6 samples were collected to enhance dependability **(ASTM C109/C109M-20b, 2020)**. Out of these, three samples were evaluated at 7 days and the other samples were tested after 28 days, as seen in **Figs. 12 and 13**.

Figure 12. Cement mortar cubes before compression testing.

Figure 13. Cement mortar cube after compression testing.

4.3.2 Split Tensile Test

Split tensile strength is a metric used to quantify the tensile strength of cement mortar. The test is frequently carried out using cylindrical specimens and serves as an indirect means of determining the tensile strength. The split tensile strength is crucial in evaluating the material's ability to withstand cracking and failure when subjected to tensile stresses. Six samples were used to enhance dependability. Three of these samples were assessed at 7 days, while the others were examined at 28 days. These testing details may be seen in **Figs. 14 and 15 (ASTM C496/C496M-11, 2011)**.

4.3.3 Density of Cement Mortar

An object's relative heaviness with respect to its volume is qualitatively characterized as its density. The impact of pulverized pumice aggregate on the density of cement mortar may be better understood by comparing various mortar mixtures using density **(BS EN 12390-7, 2019)**.

Figure 14. Cement mortar prior to split tensile testing.

Figure 15. Cement mortar cylinder following the split tensile test.

4.3.4 Brittleness Index

Brittleness is the characteristic of a substance that breaks when subjected to stress, but may exhibit a little amount of deformation before fracturing. Brittle materials exhibit properties such as limited flexibility, poor impact resistance, susceptibility to load vibrations, high compressive strength, and low tensile strength. In addition to determining the ratio between compressive strength and split tensile strength, a larger ratio indicates a greater degree of brittleness **(Karim et al., 2019)**.

4.3.5 Drying Shrinkage of Cement Mortar

The gradual loss of water content causes materials, especially cement mortar, to undergo drying shrinkage, which is characterized by a decrease in volume. We made samples for the drying shrinkage and measured each one after 7th and 28th day of their hardening using a special instrument, as shown in **Figs. 16 to 18**. This phenomenon happens when the water used in the mix or present in the material evaporates, causing the material to contract. It is crucial to know that our fundamental aim is to investigate this part in our practical work **(ASTM C157/C157M-08, 2008; ASTM C596-23, 2023)**.

5. RESULTS AND DISCUSSION

5.1 Influence of Lightweight Sand on the Properties of the Cement Mortar

Partial substitution of sand with pumice sand can impact the compressive strength, drying shrinkage, tensile strength, density, and brittleness index of the cement mortar. Choosing the best result doesn't rely on just one of these properties; it has to improve the targeted property without worsening other ones.

Figure 16. Storage of specimens for drying shrinkage.

Figure 17. The samples of cement mortar were exposed to drying shrinkage.

Figure 18. Assessment of drying shrinkage in cement mortar.

Pumice fine aggregate is softer and less dense than natural sand, and its porous structure allows it to retain water inside mortar for 28 days **(Mehta and Monteiro, 2006, Mohammed and Hamad, 2014; Higazey et al., 2020; Kadkhodaei et al., 2022; Daneti et al., 2024)**.

5.1 Drying Shrinkage of Cement Mortar

Fig. 19 illustrates the impact of partially replacing sand with pulverized lightweight pumice sand on the drying shrinkage of the cement mortar. The figure illustrates that the addition of pulverized lightweight pumice sand enhances the drying shrinkage, as it increases its ability to absorb water. However, the inclusion of pulverized lightweight sand in the cement mortar results in a self-curing method, which causes the drying shrinkage to increase beyond the baseline value. Also, the drying shrinkage of cement mortar with 16% lightweight pulverized pumice aggregate gets up to 161% better when this pulverized pumice sand is used as a self-curing agent in the cement mortar. Additionally, the cement mortar may undergo a reduction after 7 days.

In fact that the effect of the fine aggregate size on the drying shrinkage is inversely related. The value of drying shrinkage was reduced up to 50% due to adding lightweight pumice aggregate with a size range of 1.18 to 2.38 mm **(Lura et al., 2004)**. While the size of lightweight pumice aggregate decreases to lower than 1.18 mm, the drying shrinkage increases due to adding more water for internal curing, and producing more hydration, which increases the drying shrinkage as a result.

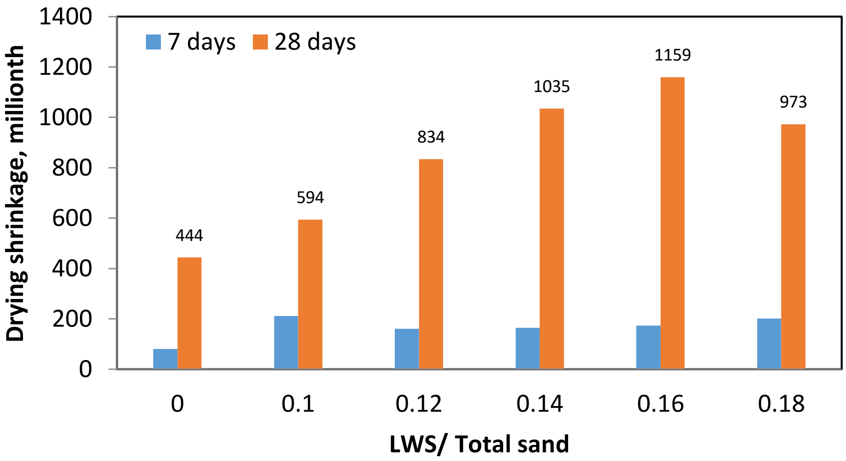

Figure 19. Effect of pulverized pumice sand on the drying shrinkage of cement mortar.

5.2 Compressive Strength of the Cement Mortar

Fig. 20 illustrates the impact of partially replacing natural sand with lightweight sand on the compressive strength of the cement mortar. The figure shows that adding pulverized lightweight pumice fine aggregate to the total amount of sand, approximately 16%, improves the compressive strength of internally cured cement mortar by up to 21.18% at 28 days. On the other hand, the partial substitution of natural sand with pulverized lightweight pumice sand at 7 days only slightly impacted the compressive strength of the cement mortar **(Karim, 2019)**.

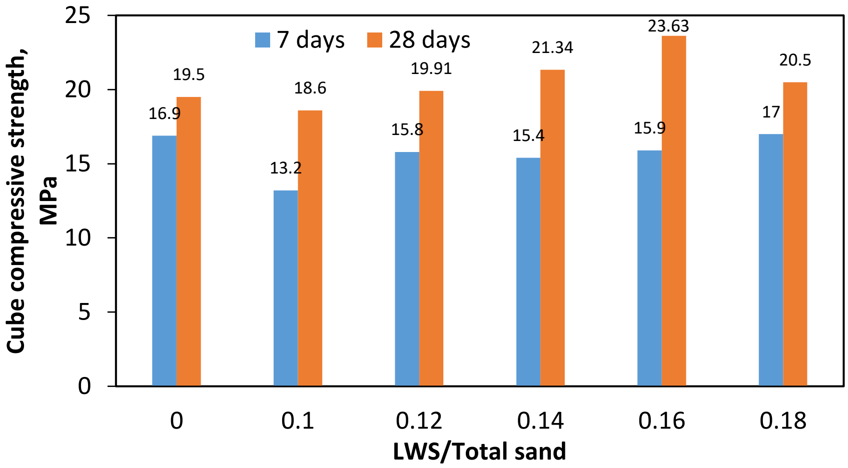

Figure 20. Effect of the partial replacement of sand with lightweight pumice aggregate on the compressive strength of cement mortar.

5.3 Split Tensile Strength of the Cement Mortar

Fig. 21 illustrates how partial replacement of natural sand with lightweight sand impacts the indirect tensile strength of the cement mortar. The figure demonstrates that the addition of pulverized lightweight pumice fine aggregate to the total amount of sand, approximately 14%, enhanced the split tensile strength of the internally cured cement mortar at 28 days by up to 18.46%. On the other hand, a partial substitution of natural sand with pulverized lightweight pumice sand at 7 days only slightly impacted the compressive strength of the cement mortar, and the addition of lightweight sand up to 16% resulted in an increase of 19.7% **(Ali and Karim, 2020)**.

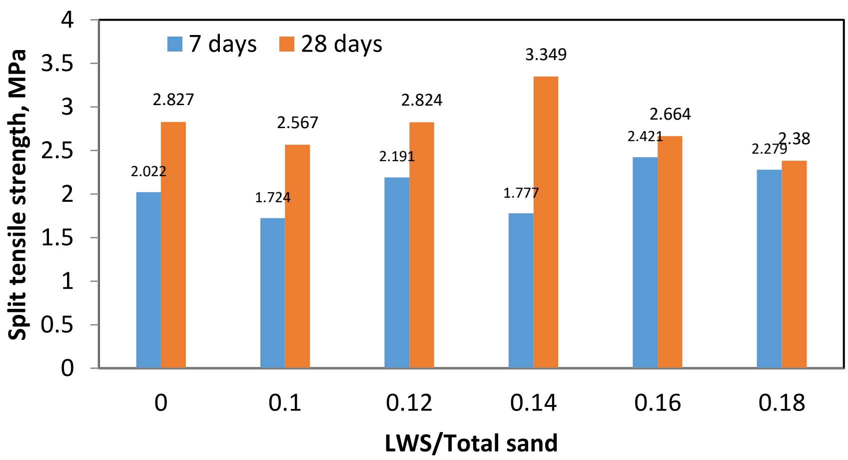

Figure 21. Split tensile strength versus the partial replacement of sand with pumice sand.

5.4 Bulk Dry Density of Cement Mortar

The partial replacement of natural sand with lightweight pumice aggregate results in improved compressive strength, split tensile strength, and drying shrinkage. However, because pumice aggregate is a lightweight material, adding it to the cement mortar may reduce its density. **Fig. 22** illustrates the impact of lightweight pumice sand on the density of cement mortar. The bulk dry density of the cement mortar decreased by 12.86% after 28 days of adding lightweight pumice fine aggregate. While this reduction in the density of the cement mortar might reduce to 13.20% due to holding water by lightweight pumice sand, which is used later for internal curing.

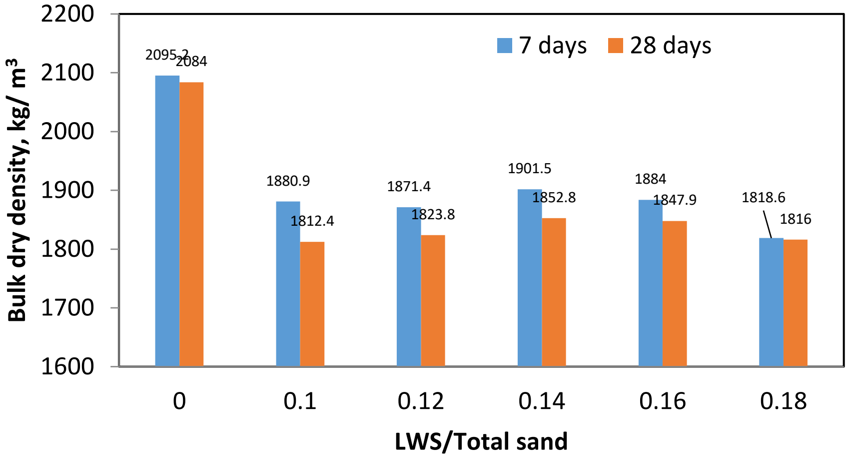

Figure 22. Density of cement mortar versus the partial replacement of sand with pumice sand.

5.5 Compressive Strength to Bulk Dry Density Ratio of Cement Mortar

It is crucial to produce new cement mortar that is both lightweight and strong, whether it is compressive or split tensile. The addition of lightweight pumice fine aggregate, approximately 16% of the total sand in the cement mortar, enhances the compressive strength to bulk density ratio by up to 36.65% at 28 days of age, thereby increasing the compressive strength and decreasing the bulk density of the cement mortar, as illustrated in **Fig. 23**. At 7 days, there was a slight change in the compressive strength to bulk density ratio.

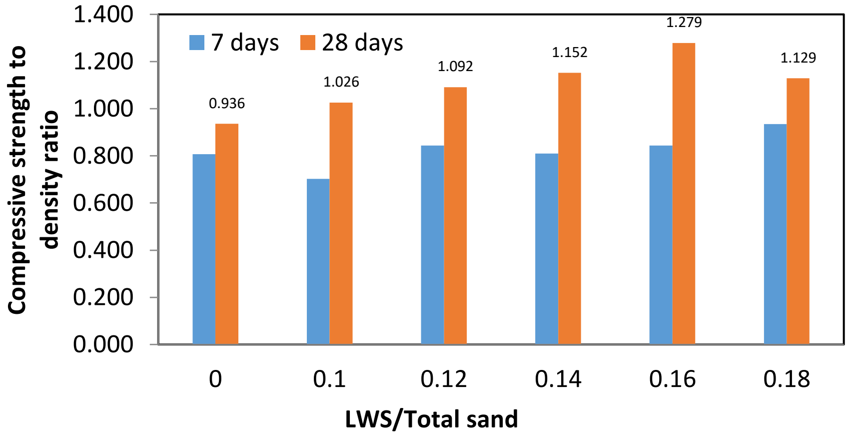

Figure 23. Effect of the partial replacement of sand with pumice sand on the compressive strength to density ratio of the cement mortar.

5.6 Split Tensile Strength to Bulk Dry Density Ratio of the Cement Mortar

Fig. 24 illustrates the impact of adding lightweight pumice fine aggregate on the split tensile strength and bulk dry density of the cement mortar. The figure shows that adding 14% of lightweight pumice fine aggregate to the total weight of sand in the cement mortar improves the split tensile strength to bulk density of the cement by up to 33% at 28 days of age. Furthermore, it's possible that the same level of improvement will occur when the cement mortar ages by 7 days.

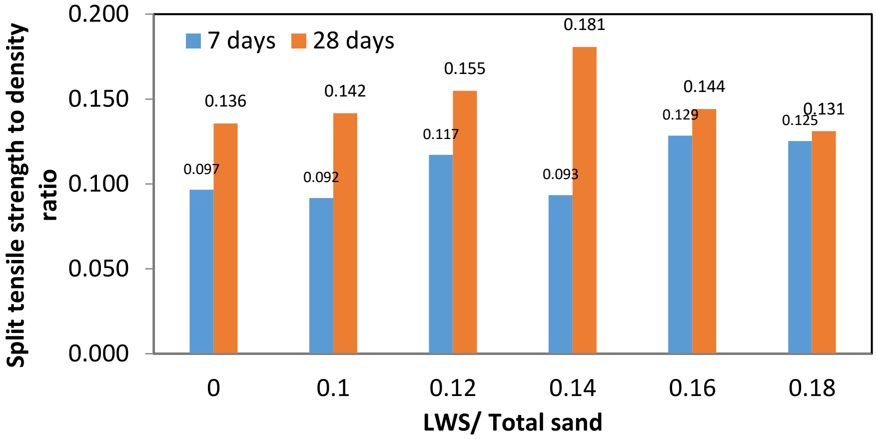

Figure 24. Effect of the partial replacement of sand with pumice sand on the split tensile strength to density of the cement mortar.

5.7 Brittleness Index of the Cement Mortar

The general brittleness index of concrete is the ratio of compressive strength to tensile strength **(Karim et al., 2019)**. **Fig. 25** illustrates the influence of lightweight pumice sand on the brittleness index of the cement mortar. The inclusion of lightweight pumice sand in the cement mortar, which contributes up to 16% of the total weight of the natural sand, increases the brittleness index by up to 29% at 28 days of age. The addition of lightweight sand to the cement mortar, up to 16%, reduces the brittleness index by up to 21% after 7 days, enhancing the tensile strength and marginally increasing the compressive strength, as illustrated in **Fig. 25**. This helps the mortar to resist movement, such as during the earthquake.

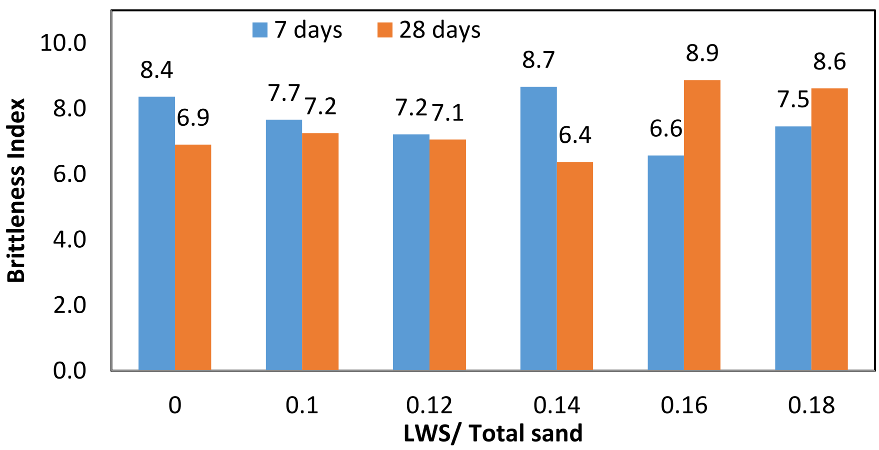

Figure 25. Brittleness index of cement mortar versus the partial replacement of sand with pumice fine sand.

6. CONCLUSIONS

A study was done to assess the influence of pulverised lightweight pumice stones on the mechanical and non-mechanical properties of cement mortar. The subsequent conclusions may be inferred. Adding pulverized lightweight pumice stone to cement mortar, up to a concentration of 16%, improves the compressive strength by 21.18% and the split tensile strength by 18.5%. The density of the cement mortar decreases by roughly 9.7%. Nevertheless, the brittleness index of this cement mortar drops by 22%, showing a substantial increase in ductility. The substitution of lightweight pumice stone somewhat enhances the drying shrinkage of cement mortar by a maximum of 161%. In addition, using lightweight sand can absorb water more effectively than natural sand, which might result in an escalation of shrinkage. This emphasizes a significant challenge in maintaining the mortar's dimensional stability.

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Declaration of Competing Interest

The author declares that he has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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تأثير الحصى الناعم الخفيف المسحوق على الانكماش الجاف لملاط الأسمنت

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الخلاصة

إن استخدام المواد الخام خفيفة الوزن في تصنيع الخرسانة الأسمنتية يحل مشكلة انكماش الجفاف على مدى عمر الخرسانة، ومع ذلك فإن استخدام الرمل الصناعي خفيف الوزن قد يزيد من هذه المشكلة في ملاط الأسمنت. يبحث هذا البحث في كيفية تأثير استخدام الرمل الخفيف على الصفات غير الميكانيكية لملاط الأسمنت، وهي خاصية الانكماش الجاف. تم تحضير الرمل خفيف الوزن عن طريق سحق حجر الخفاف، وغربلته من خلال منخل 1.18 مم، ودمجه مع الرمل الطبيعي العادي بكميات متفاوتة. تم اختبار نسب استبدال مختلفة للرمل خفيف الوزن حسب الوزن، مثل 10٪، 12٪، 14٪، 16٪، و 18٪، مع الاحتفاظ بعينة تحكم واحدة بدون أي رمل خفاف مسحوق خفيف الوزن. مع زيادة نسبة المواد الخام خفيفة الوزن الخفاف المسحوق، فإن الانكماش الجاف لملاط الأسمنت الذي يحتوي على مواد خام خفيفة الوزن الخفاف المسحوقة يزداد بنسبة تصل إلى 161٪، مما يؤثر سلبًا على متانة ملاط الأسمنت على الرغم من تحسن قوى الشد الانقسام و الانضغاطية لملاط الأسمنت. علاوة على ذلك، انخفضت قيمة مؤشر هشاشة ملاط الأسمنت بسبب تحسن قوة الشد المشقوقة. ومع ذلك، انخفضت الكثافة الجافة الكلية لملاط الأسمنت بنسبة تصل إلى 13.2٪، مما يدعم تقليل الحمل الميت في المباني الشاهقة.

الكلمات المفتاحية: ملاط الأسمنت، انكماش التجفيف، رمل الخفاف الخفيف المسحوق، حجر الخفاف.