

Utilization of Ceramic Tiles Waste Powder on Mortar Concrete using North Sinai Materials

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Keywords: workability, compressive strength, shrinkage, Ceramic waste powder, flow.

Abstract. Growing populations worldwide need housing, infrastructure, and essential services. This rapid growth has stressed the environment and limited the availability of construction materials. As a result, it's becoming increasingly important to research environmentally friendly engineering methods. Another option is using large amounts of ceramic tile waste powder from construction and demolition projects. Previous studies had shown that these waste materials had pozzolanic properties, which means they could potentially be a substitute for cement in construction. This study looked at compressive strength, how strength changed over time, and how well the mortar flowed. In our study, we replaced a portion of the cement with ceramic powder, using amounts from 0% to 50% of the total weight, with increments of 10%. Standard cube specimens of 70 × 70 × 70 mm were fabricated and subjected to water curing until the specified testing ages. Our results showed that 20% waste ceramic powder as a replacement represents the best result compared to other results of mortar mixes, illustrating that finely processed ceramic waste can serve well as a supplemental cementitious material. This suggests the potential to improve sustainable building methods while reducing reliance on traditional cement.

1.Introduction

An intriguing supply is demolition debris, where ceramic materials dominate due to Egypt's traditional building practices and outdated production technologies. The advancement of cement and concrete technology can reduce the consumption of natural resources. They must prioritize industrial waste recovery, reuse, and alternative solutions. Interestingly, using replacement materials can result in cost savings, energy savings, better goods, and reduced environmental hazards. The most common building materials in the world are concrete and mortar. Still, it is not an environmentally friendly material because it degrades and uses up large quantities of natural resources. It is also a source of environmental impact because, after its use, it is generally deposited in landfills [1]. It is estimated that approximately 31% of daily production in Egyptian ceramic companies is wasted, with a variance of ±5.0% among countries worldwide. Ceramic wastes (CW) are currently not subjected to any sort of recycling. Nonetheless, ceramic waste is resilient, hard, and exhibits significant resistance to biological degradation, possessing pozzolanic qualities due to its substantial content of reactive silica oxide with minimal impurities [2]. According to the findings of the earlier research that relied on ceramic waste, it was discovered that ceramic waste possessed pozzolanic qualities [3, 4]. The tests were carried out with ceramic waste that had a size that was

higher than 40 μm . However, this research's task undertook the influence of ceramic waste that had a size of less than 40 μm . Physical and chemical deterioration. As ceramic waste accumulates daily, producers have the issue of finding an environmentally and economically viable disposal method. Presently, typical crushed stone aggregate stocks are rapidly diminishing, especially in desert locations [5]. The most efficient replacement or alternative for OPC materials was natural or artificial pozzolan resources [6]. Clay minerals are mostly used in ceramic manufacture due to their crystalline structure, pozzolanic characteristics, and glassy particles in their native state. They exhibit high pozzolanic activity when calcined at 600-900 °C and milled to cement fineness [7]. The usage of ceramic powder as a partial replacement for cement in mortar has a significant influence on both fresh and hardened properties. Generally, all mixes containing ceramic powder show noticeable changes depending on the replacement level. Ceramic powder marginally improves workability in fresh properties owing to its tiny particle size, which improves particle packing and reduces internal friction. This yields a more unified and uniform mixture in comparison to the control. The impact of ceramic powder on mechanical performance is contingent upon the replacement ratio. At low to moderate concentrations, ceramic powder can preserve or marginally enhance strength owing to its filler effect and possible pozzolanic activity, which aids in the formation of supplementary binding products. However, at a high percentage, the replacement of ceramic powder affects the mechanical properties of concrete, such as compressive strength, due to the reduction of cement content. For durability, ceramic powder improves the internal microstructure by filling voids and refining pore distribution, which reduces permeability and limits moisture movement. This leads to better dimensional stability, including reduced drying shrinkage. Overall, ceramic powder is an effective, sustainable material that enhances microstructure and durability while maintaining acceptable mechanical performance at optimal replacement levels. However, excessive replacement may negatively affect strength due to reduced cementitious content [9,8]. Not only does the incorporation of ceramic waste powder into concrete serve as a partial replacement for cement, but it also affects the hydration process. Nature's powder, as ceramic powder, reacts with calcium hydroxide (CH) that is formed during the cement hydration process. Also, the reaction formed calcium silicate hydrate (C-S-H), which is the principle of strength and durability of concrete. Early hydration was observed in the formation of (CH) and (C-S-H), especially in the usage of percentages of ceramic powder in the range of (5-15) % as a replacement. Microstructure was investigated to show the effect of reaction on the potential to positively alter the hydration kinetics and microstructure of concrete. This makes ceramic powder a suitable supplemental cementitious material (SCM) that improves both mechanical performance and sustainability [10].

2. Materials

Ceramic Powder. The ceramic waste was crushed in a jaw crusher and subsequently sieved using a 1.18mm sieve to eliminate the larger particulates. Subsequently, the ceramic was ground in the

modified Los Angeles abrasion test machine using six stainless steel rods that were 800mm in length and 18mm in diameter[8, 9]. Only the fine ceramic that 90 percent passed through the 45 μm sieve was collected and used in themixing[11, 12]. After treatment, the ceramic powder exhibited a dark grey hue that was nearly identical to that of standard Portland cement. The ceramic powder was employed as a substitute for cement after it was ground [10, 11]. The optimal combination proportion was achieved by varying the percentages of replacement. Table 1 illustrates the chemical compositions of ceramic and cement [12, 13].

Table 1. Chemical composition of ordinary Portland cement and ceramic waste powder

Properties	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	SO ₃	K ₂ O	Na ₂ O	TiO ₂	LOI
Cement %	22	4.60	3.50	61	3.34	3.15	0.80	0.91	-	0.70
Ceramic Powder	74.2	17.7	5.57	1.12	-	-	2.70	-	0.45	0.1

The North Sinai sand that is readily available in the region and is in the surface dry condition (SSD) is the sand that is employed. As a result of the fact that this particular condition of fine aggregates is the best in mortar mixes, this indicates that it does not impede the functionality of the mixture and, consequently, the strength of the mortar. On account of the fact that it prevents the mixture from absorbing an excessive amount of water while it is being mixed, this is the benefit. The size of the sand that was used for casting applications was arranged in a manner that conformed to the ASTM C33-03 Standard Specification for Concrete Aggregates [14]. The sieve analysis graph that was calculated for the sand, as shown in Figure.1, was utilized in this experiment. It is estimated that sand has a bulk density of 1700 kilograms per cubic meter.

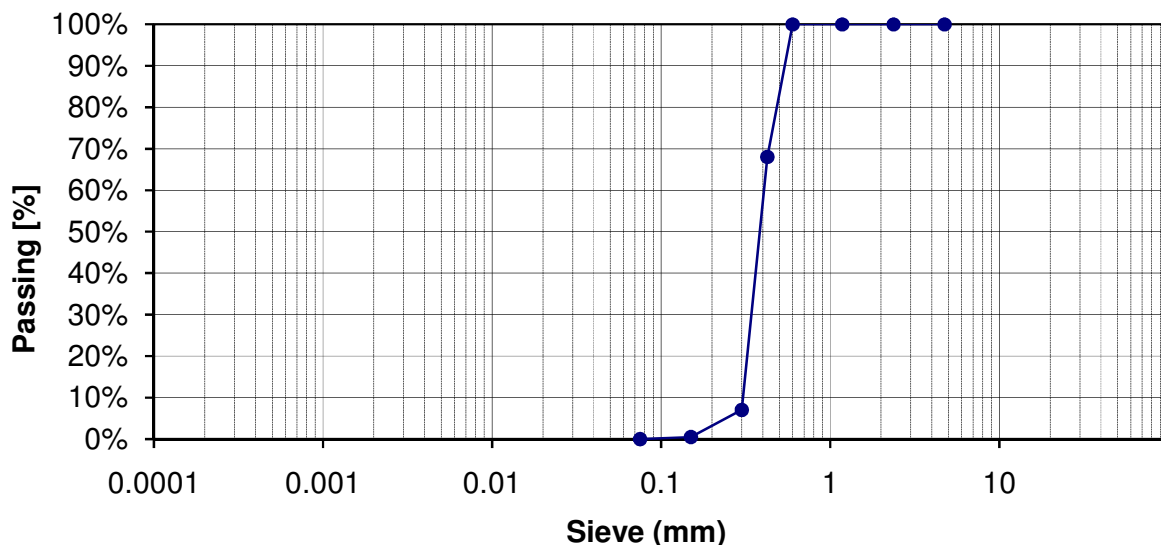


Figure 1. Sieve analysis curve of sand

3. Mixing proportions and methodology: To investigate the mortar combinations, a 20-liter mechanical mixer with a rotational speed of 80 revolutions per minute is used. In accordance with the ASTM standard C1329/C1329M-12, [15] all sampling and testing were carried out. Before the addition of water, the cement, ceramic powder, and sand were completely combined and stirred for

approximately two minutes. After that, water was added to the mixture, and it was stirred for a further five minutes. In accordance with the ASTM standard C109/C109M-11b [15], the mortar specimens were constructed by employing cubes of 50 mm x 50 mm x 50 mm. The specimens on the test. The mortar's air cavity was eliminated by compacting the material for thirty seconds using a vibrating table. In order to endure testing, the specimens were extracted from the molds and stored in a water tank until the following day, twenty-four hours after the casting process. The mortar mix proportions that were employed in the investigation are illustrated in Table 2.

Table 2. Mixproportionsofmortar

Mix	OPC	Replacement %	CeramicPowder	Sand	w/cratio
CP0	650	0	-	1750	0.42
CP1	585	10	65	1750	0.42
CP2	520	20	130	1750	0.42
CP3	455	30	195	1750	0.42
CP4	390	40	260	1750	0.42
CP5	325	50	325	1750	0.42

Determination of Workability and Strength.

An investigation into the workability of hydraulic cement in terms of flow was carried out in line with the ASTM C230/C230M-08 [16]. At the ages of 7, 28, 56, and 90 days, the compressive strength test was carried out in accordance with ASTM C 109-11 [15]. Tests were performed on three different specimens in order to get the average value for each test condition. To evaluate drying shrinkage of the blended binder, prismatic specimens of 40 × 40 × 160 mm were used, following ASTM C157/C157M [17]. After 24 h of curing, the specimens were placed in a 25 °C, 28% relative humidity environment. To establish the blended cement systems' maximum drying shrinkage, linear shrinkage was measured.

4. Results and Discussion

Microstructure of ceramic powder. As shown in Figure. 2, the field emission scanning electron microscopy (FESEM) technique was utilized in order to analyze the morphology of the ceramic powder. The specimens that were acquired from the compressive strength test had a coating of gold applied to their surface before the morphological examination of the specimens was performed. It had been demonstrated that the ceramic powder is made up of particles that are both irregular and crushed.

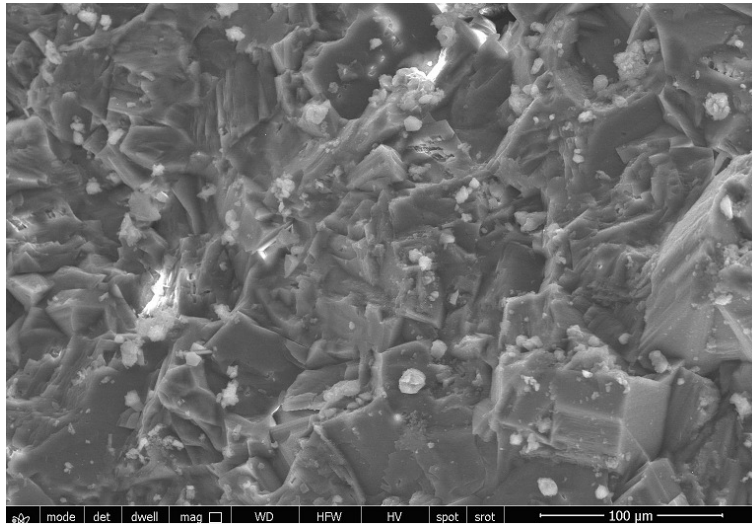


Figure 2. Field Emission Scanning Electron Micrograph of mortar with ceramic waste powder

Workability of mortar. Figure 3 shows the flow results of mortar with ceramic powder compared to regular Ordinary Portland Cement (OPC) mortar in figure 3. It presents the flow spread diameter of mortar mixtures, which included ceramic powder as a partial cement replacement, compared to the control mix (CP0). A clear decrease in workability was shown when the amount of ceramic powder increased from 0% to 50%. The control mix (CP0), with the highest flow value of about 250 mm, indicates the best workability. The flow value slightly decreased to about 246 mm with a 10% replacement (CP1), which caused a reduction of 1.6% compared to the control. This small decrease suggested that the effect of low amounts of ceramic powder on workability was limited [18]. The flow value diminished further, reaching roughly 243 mm with a 20% replacement level (CP2), representing an approximate 2.8% decrease. When 30% ceramic powder replacement was used in the mix (CP3), the flow was around 240 mm, which was about 4% less than that of the mix (CP0). For mix (CP4), when 40% is replaced, it shows a flow value of approximately 238 mm, corresponding to a reduction of roughly 4.8%. Finally, (CP5), at 50% replacement, records the lowest flow value, nearly 235 mm, thereby indicating a total reduction of approximately 6% [19]. This downward trend persisted at higher replacement levels. The increased water demand of ceramic powder, which was a result of its finer particulate size and larger specific surface area, can be attributed to the continuous decrease in flowability. Furthermore, the ability of the material to absorb water reduced the amount of pure water available for lubrication in the mixture [15]. The results generally suggest that the mortar's workability decreases as the amount of ceramic powder increases. However, this decrease was moderate, indicating that partial replacement is feasible within acceptable limits [20-24].

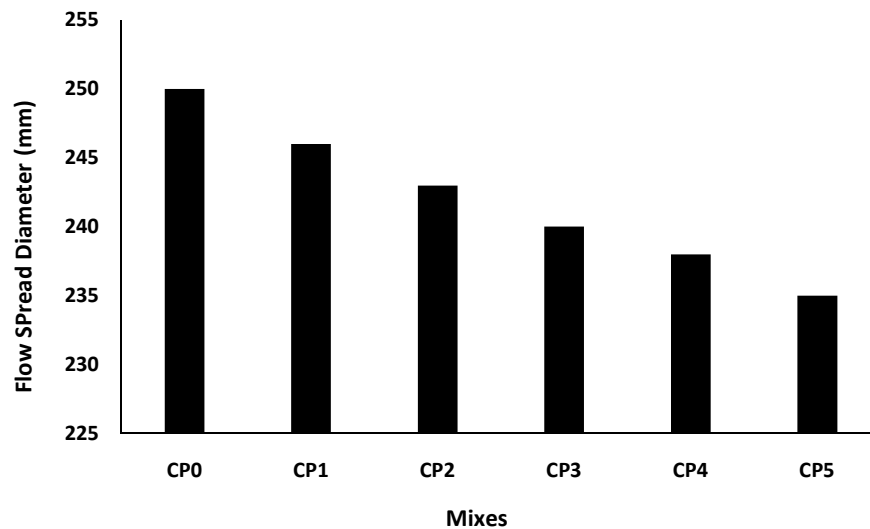


Figure3.Flowresultofthe mortar

Compressive strength. The results of the mixtures that used ceramic powder to partially replace cement, with replacement levels ranging from (CP0), (the control), to CP50%. The control mix (CP0) represented the mix without any replacement or addition as the standard for comparison. Generally, as shown in the figure. 4, results show either a significant improvement in comparison to the control mix at a 10% replacement level (CP10%), which is attributed to the pozzolanic activity of ceramic powder, which contributes to the formation of additional calcium silicate hydrate (C–S–H), thereby improving the microstructure. The best percentage that was used, which represents a more significant impact, is evident when the replacement level is elevated to 20% (CP20%). Performance typically declines slightly, ranging from 5% to 10% when compared to the control. This was attributable to the reduction in cement content, notwithstanding the ceramic material's continued, albeit minor, contribution via pozzolanic reactions. The reduction becomes more pronounced at a 30% replacement (CP30%), typically ranging from 10% to 20% relative to CP0. The mechanical properties declined as a result of the substantial decrease in cement content, which is no longer compensated for by the pozzolanic reaction at this stage. A substantial decline in performance is observed at higher replacement levels, such as 40% and 50% (CP40% and CP50%). Compared to the control mix, the diminution may vary from 20% to 40%. This is primarily attributable to the substantial reduction in the quantity of cement that is available for hydration, which leads to a decrease in the production of binding compounds that are responsible for the development of strength. In general, it can be inferred that the most effective replacement level of cement with ceramic powder is between 10% and 20%. This level strikes a balance between sustainability (reducing cement consumption) and the preservation of satisfactory mechanical performance. The detrimental effects on the properties of concrete become increasingly apparent as the spectrum extends [20, 21]. The strength was significantly greater than that of standard OPC mortar after 7 days when 20% of ceramic powder was substituted. It was a result of the high concentration of aluminum oxide (Al_2O_3) in ceramic particles, which induces early strength.

However, the samples that contain a significant volume of ceramic powder replacement also contain aluminum oxide; however, the quantity of calcium hydroxide present is insufficient to initiate a reaction and produce calcium aluminate hydrates [26 ,25].

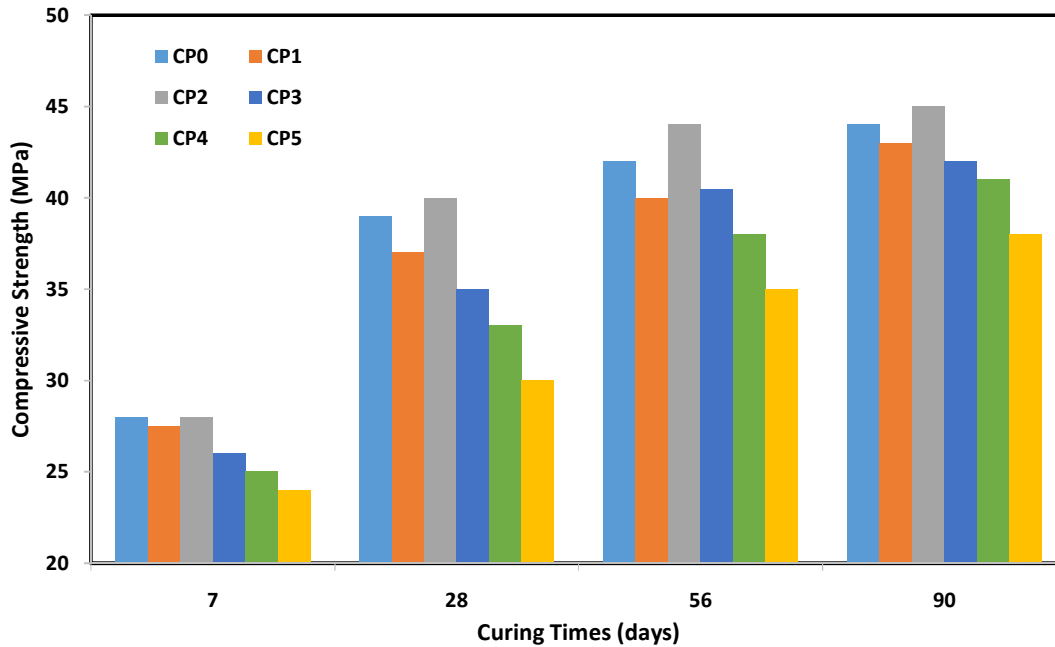


Figure4.Compressivestrengthofmortar

Strength development: Figure 5 illustrates the development of mortar strength, indicating an increase in compressive strength at a later age. The specimens were immersed in water for curing durations of 7, 28, 56, and 90 days. The enhancement in the strength of ceramic mortar resulted from the pozzolanic reaction between silicon oxide and calcium hydroxide, which generated additional Calcium-Silicate-Hydrate ($3\text{CaO}\cdot 2\text{SiO}_2\cdot 4\text{H}_2\text{O}$, sometimes referred to as C-S-H gel), hence increasing the density of the mortar [22, 23]. In addition, the unreacted ceramic powder acts as a filler in the sample, which leads to denser mortar, resulting in higher strength [27, 28].

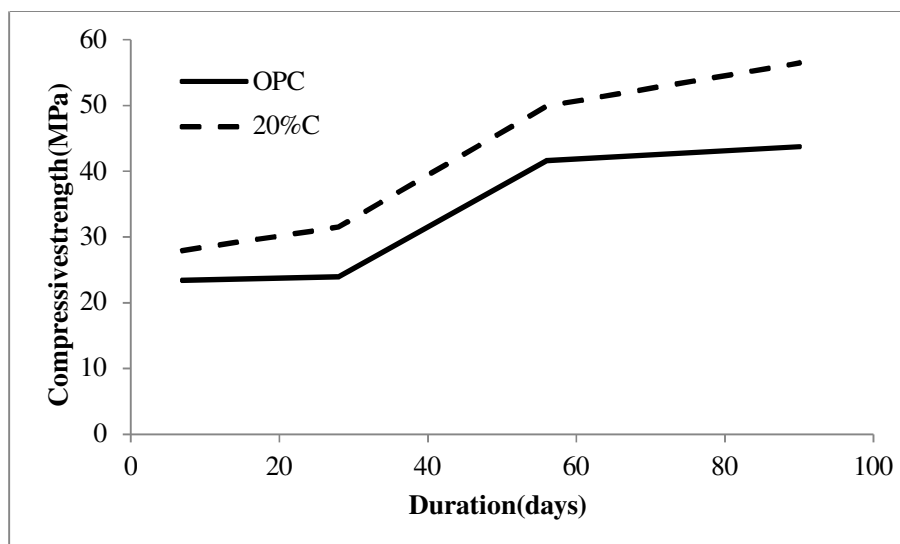


Figure5.StrengthdevelopmentofOPCmortarand20%replacement.

Effect of Ceramic Waste Powder on Drying Shrinkage:

The figure illustrates the temporal development of drying shrinkage (mm/m) across mortar mixes with differing proportions of ceramic waste powder, designated as (CP0) (the control) and (CP1–CP6) (the replacement levels). All mixtures exhibit a consistent trend, initially experiencing a substantial increase in drying shrinkage during the first 40 days, followed by a more gradual and consistent rise until the 35-day curing age. The highest shrinkage values were for the control mix (CP0), consistently displayed throughout the entire duration, reaching approximately 2.45 mm/m at 35 days [29]. This observation can be largely attributed to the elevated cement content, which promotes increased hydration and, consequently, greater shrinkage. Conversely, all mixtures with ceramic powder exhibit less shrinkage relative to the control. In the initial curing ages, as shown from 3 to 7 days, the decrease is evident, with measurements approximately between 0.64 mm/m and 1.15 mm/m, constantly below the mix (CP0)[30]. This pattern persists in later ages. Conversely, the modified curve suggests that the reduction in shrinkage does not follow a consistently linear trend as the replacement increases. While mixtures like (CP5) and (CP6) generally show diminished shrinkage, certain intermediate mixes, such as (CP2) and (CP1), may, at particular ages, exhibit slightly higher values relative to others. Shrinkage measurements at 35 days for the modified mixes range from approximately 1.92 mm/m to 2.18 mm/m, representing a decrease of roughly 10% to 20% when compared to the control mix. The reduction in drying shrinkage is attributed to two primary factors: the decreased cement content, which lessens shrinkage caused by hydration, and the filler effect of ceramic powder, which improves particle packing and reduces moisture movement within the matrix. The results demonstrate that the incorporation of ceramic waste powder substantially diminishes drying shrinkage, although the improvement is dependent on the replacement level and is not perfectly linear. When using high replacement ratios, mixes (CP5) and (CP6) consistently demonstrate the best performance in enhancing dimensional stability [31].

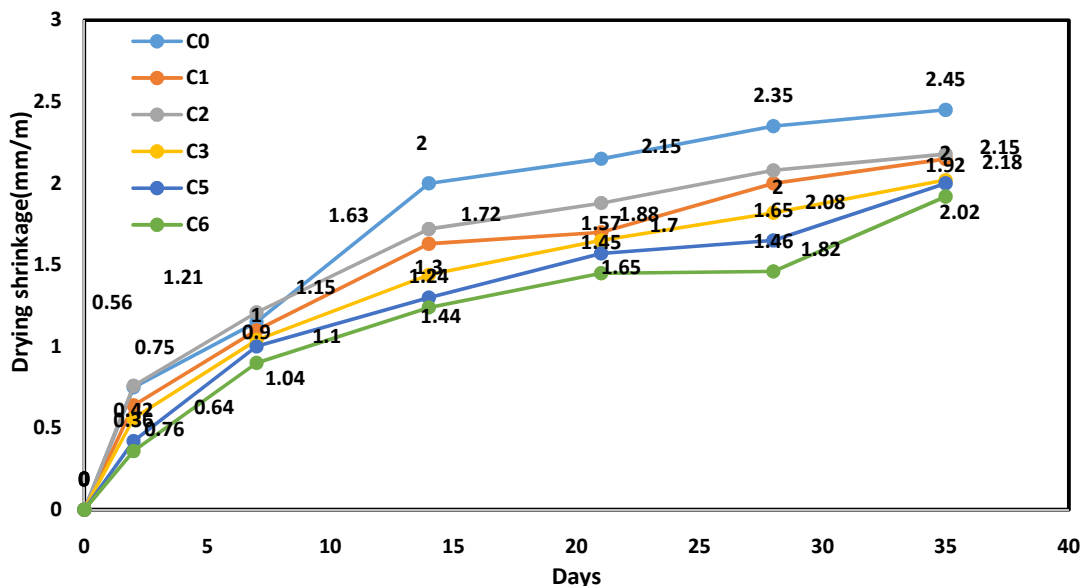


Figure 6. Drying shrinkage of OPC mortar mixes with curing ages.

5. Conclusions

From the results, the conclusions are selected in the following items:

- 1- Replacing cement with ceramic powder has improved the mortar workability and reduced drying shrinkage.
- 2- The results of flow value were decreased from around 250 mm to 235 mm at 50% as a replacement with ceramic powder compared to the control, a reduction of about 6% overall. At moderate levels from 10 % to 20%, variance results in between 1.5% and 3%.
- 3- In contrast, drying shrinkage had significantly improved. Consequently, ceramic powder proved most efficacious at replacement levels ranging from 20% to 40%, yielding a substantial reduction in shrinkage while maintaining sufficient workability.
- 4- The microstructure showed that it was improved, and C–S–H formation was enhanced by pozzolanic reactions, resulting in the optimum compressive strength being obtained at from 10% to 20% cement replacement with ceramic powder.
- 5- When 20% replacement by ceramic powder content with cement content, it was found that increasing the replacement beyond 20% leads to a gradual and then significant reduction in strength due to the decrease in cement content and insufficient pozzolanic compensation. At higher levels (40–50%), the strength drops markedly (up to 40%) because of limited hydration products and weaker binding matrix formation.

Limitations and future work

This investigation was restricted to specific ceramic particle replacement levels (up to 50%) and concentrates primarily on drying, compressive strength, shrinkage, and workability of mortar. We recommended investigating the ceramic powder in other investigations, as flexure strength, indirect tensile strength, durability, and permeability were not examined, despite their significance. Moreover, the experiments were performed in controlled laboratory settings, which may not reflect real-world conditions. Future studies should primarily concentrate on assessing durability factors, such as long-term strength, chloride penetration, and sulfate resistance. Further research is advised to refine the mix design parameters and investigate the synergistic application of ceramic powder with other auxiliary materials.

Acknowledgements

The authors are deeply appreciative of Sinai University's unwavering support and encouragement. The Faculty of Engineering is particularly acknowledged for its provision of the requisite academic environment and facilities to facilitate the conduct of this research. The authors also express their gratitude to the Materials Laboratory personnel for their technical support and collaboration during the experimental work.

Declaration of Competing Interest:The author declares that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability: Please contact the author with any questions on the availability of the data.

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