

Enhancing Curing Methods for Cement Mortar: Integrating Self-Curing Agents for Better Performance

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Abstract

The work examines the early-age mortar properties in order to study the effect of self-curing agents and their possible application as internal curing agents. Some challenges in the curing of cement mortar include the influence of moisture loss and environmental conditions on mechanical integrity. The self-curing mortars, thus, seem to offer a way out by using additives that promote internal moisture retention for better performance and durability. This paper primarily discusses the effectiveness of SCA in mitigating capillary stress and autogenous shrinkage, with emphasis on the involvement of pore structure and water absorption during hydration in cements. The materials considered in this research include cementitious materials, while the curing agents are SAPS and two types of polyethylene glycols, namely PEGL and PEGP added at different concentrations. Compressive strength, water absorption, and other tests have been carried out on mortars cured in air and water for a period of 56 days. Results have indicated that 0.3% of SAPS, 1.0% of PEGL, and 1.0% of PEGP yield significantly higher compressive strength, especially under proper curing conditions. The water curing has higher strength compared to air curing in all cases; thus, curing is an important role player in the giving of properties to mortars. The present study concludes that self-curing mortars may present potential for sustainable construction but additives and curing conditions have to be carefully selected. The best performance from Table 6 was recorded for PEGL-modified PPC, and it is expected that reliance on traditional, labor-intensive external curing will be minimized by adopting self-curing methods to improve construction efficiency and sustainability.

1. Introduction

Curing is the important process to be undertaken by cement mortar to achieve proper strength and durability. The hydration of the cement particles in developing its micro structure and mechanical properties is essential [1]. However, there exist several challenges to the curing process, which generally emanate from water loss through evaporation, which under certain hot or windy conditions may occur rapidly [2]. Inadequate moisture retention can cause surface cracking, hence compromising the integrity of the mortar with increased permeability to environmental damage [1]. The most important environmental factors influencing curing are temperature fluctuations and low humidity, which cause increasingly inconsistent moisture conditions that affect mechanical properties [3]. Conventional curing techniques need much labor and monitoring in efforts to maintain optimum moisture levels, hence complicating construction schedules and often delaying processes [4]. Apart from this, the use of poor quality curing materials might further worsen the loss of water [5]. If the resolution of these issues is

achieved, then it will definitely assure better performance and durability for the cement-based materials in construction.

Great resource problems have occurred in the building industry, including over exploitation of natural sand and stone and production of huge quantities of construction wastes from demolished buildings due to rapid urban development. It is estimated that in mainland China, about 200 million tons of recycled concrete are obtained every year from renewal works in urban areas [6]. This situation is aggravated by disasters of earthquakes, which further raise wastes of concrete [7]. It is widely believed that effectively utilising the recycled aggregates will decide how the problems of consumption of resources and generation of waste in construction would be solved to promote sustainable development [8].

It has been proved by research that this type of recycled coarse aggregate can be gainfully utilized in the production of conventional and even high-strength concretes, provided it is properly designed and constructed. Recycled fine aggregate creates different problems: because of the higher water absorption rate of RFA, from 6% to 13% compared with natural sand, more mixing water is required, badly affecting workability and the performance of cement-based materials [9]. It has been observed that with the increase of RFA content, strength, shrinkage, and durability decrease, and hence its use in mortar and concrete requires some dosage limits [10]. Various authors have mentioned that RFA water content and saturation conditions are critical factors to be controlled in order to optimize the performance of RFA in cement-based materials [11]. Indeed, some have found that the utilization of saturated recycled aggregates can affect the strength of concrete negatively due to the leaching of water from the aggregates into the fresh mix [12]. Proper internal curing can somewhat mitigate some of the negative effects of RFA by allowing the continued hydration of cement with time [13]. It is considered, however, that due to their pore structure, the performance of recycled aggregates as internal curing materials is limited [14]. Recycled aggregates can give sustainability to this solution, but on the other hand, their application in cement-based mixtures requires careful consideration of properties and behavior.

The construction industry is in continuous pursuit of materials that would improve performance while responding to sustainability challenges. Conventional cement mortar needs curing with care in order to provide sufficient hydration, which is absolutely necessary if the desired mechanical properties and durability are to set in, according to [1]. However, conventional curing methods are quite labor-intensive and heavily affected by environmental conditions, therefore really vulnerable to defects such as cracking and variable quality [1].

These lead to the development of self-curing mortars that are made of materials which allow the retention of moisture within the mix itself. This, therefore, creates minimal dependence on external methods for curing, hence reducing labor and improving efficiency in construction [15]. Research has indicated that the self-curing mortars can improve hydration and, consequently enhance compressive strength coupled with reduced shrinkage, as compared to conventional cement mortars [16]. The inherent properties of self-curing formulations, including maintaining moisture, not only reduce the possibility of defects caused by rapid evaporation but also improve reproducibility for a wide range of environmental conditions.

Moreover, self-curing mortars can ensure the optimization of water usage in addition to minimizing waste that might be generated from traditional curing methods. Based on several works, the addition of self-curing agents into cement-based materials enhances the durability performance of such materials due to the capability to resist environmental-related degradation processes [17]. For this reason, with the increasing demand for high-performance and sustainable building material, self-curing mortar has been proved to be an alternative facing better serviceability and longer service life in different construction applications.

The present experimental research work has been carried out to investigate the effects that RFA in a saturated condition could induce on early-age mortar, considering its role of internal curing material. For this purpose, RFA is subjected to tests about pore structure and isothermal desorption at different RH conditions, together with investigation on the efficiency of internal curing with saturated RFA concerning capillary stress and autogenous shrinkage. The theoretical internal curing water was added to the mixture to investigate the maximum influence of RFA, as well as the influences of RFA particle size and water absorption capacity on shrinkage. The primary issues were resolved, cement mortar needs a consistent and adequate supply of moisture to fully hydrate during curing. Inadequate moisture leads to incomplete hydration, which results in decreased strength and durability. Materials or methods that improve moisture retention during the curing process may be the subject of future research. In some circumstances, like as remote locations or throughout the winter, proper curing may be challenging. Research may examine curing techniques or additives that enhance performance under such conditions.

2. Materials and Methodology

2.1 Materials

Temperature and moisture content of cement mortar should be maintained correctly for the right hydration to take place in the cement. The mortar is allowed to develop its strength through proper curing, thus creating a strong product. The following materials were used: OPC with a specific gravity of 3.10 g/cm³ was used in this investigation, PPC, Sand, which was used into three size fractions: 1.18–2.36 mm (R1–1.28), 2.36–4.75 mm (R1–2.36), and 0.6–1.18 mm (R1–0.60).

2.2 Procedures for Mortar Casting and Testing

The process of casting self-curing cement mortar is quite challenging; hence, it provides accurate test results. The materials to be used, which include self-curing agents, cement, fine aggregates, and water, should be weighed first, as required in the intended mix design. The mix is first prepared by incorporating the dry ingredients, which include cement and aggregates, to ensure uniformity in the distribution of the material. The self-curing agent was first mixed with the water to enhance hydration before mixing it with the dry ingredients. This method reduces the need for extra curing by effectively sealing moisture within. The mixed mortar shall be filled into molds, cubical, 50 mm, as per ASTM C109. In filling, any air pocket that will weaken the specimens should be carefully avoided.

Some tests can be carried out to evaluate the physical properties of self-curing cement mortar, including specific gravity and distribution in the size of the particles. Specific gravity can be determined by weighing the sample of cement with water which displaces it in a pycnometer according to ASTM C188. Moreover, ASTM C136 enables the finding of the distribution of the size of the gains through passing the sample through several screens. These tests give the appropriateness of the material in construction. To identify the performance characteristics, the chemical composition of the mortar must be analyzed using methods described in ASTM C 114. Techniques generally involve wet chemistry to quantify major oxides such as SiO₂, AlO₃, CaO, and MgO.

2.3 Assessing the Strength of Fresh and Hardened Mortar

The workability of fresh mortar can be checked by the flow table test according to ASTM C1437, where the freshly prepared mortar is poured into a flow table mold. Then, the mold must be leveled and raised to allow the mortar to flow. The diameter obtained from the spread will then be measured to determine its workability. Another slump test according to ASTM C143 consists in filling a slump cone with mortar and then taking out the cone and measuring the vertical drop. All the tests ensure that the mortar can be correctly placed, compacted at construction. One of the most important measures of performance of self-curing cement mortar is its compressive strength. The final set mortar cubes are tested after specified intervals like seven and twenty-eight days, in accordance with the testing criteria of ASTM C109. The cubes are placed in a compression testing apparatus and the highest load applied to achieve failure is recorded. Water Absorption Tests One of the major properties which impact durability is the water absorption of the self-curing cement mortar. This test follows the methods described in ASTM C642. After curing, the dry weight of the mortar specimen is recorded. Then, it is submerged into water for a complete day in order for it to completely saturate. It is weighed after removal and wiping off any water on its surface as its saturated weight.

3. Results and Discussion

3.1 Physical Properties

OPC, M1, shows a general consistency of 30%, which is taken as a reference. The normal consistency values are generally higher in the SAPS series, with the highest at 36% for SAPS 0.3 (M4) are shown figure 1. In contrast, normal consistency values of PEG L and PEG P series show variations between 31% and 34.5%. The initial setting time is the time taken by the cement to begin hardening. The initial set up time for OPC is 170 minutes. Setting times are generally higher for the SAPS series, with SAPS 0.2 (M3) taking 220 minutes as the highest. For the PEG L series, the initial setting times are quite variable; it takes 230 minutes for PEG L 0.75 (M8). This can also be seen in the PEG P series, where PEG P 0.75 is seen to have an initial setting time of 200 minutes. In the final setting, this is because the cement has attained its complete setting and hardening. In OPC, this is achieved after a total of 250 minutes. Among the SAPS series, M3, which has a SAPS content of 0.2, and M5, which contains 0.4 SAPS, have final setting times of 320 minutes and 220 minutes, respectively [18].

The PEG L and PEG P series also exhibit a range with the longest times being 310 and 320 minutes for PEG L 0.75 (M8) and PEG P 1.25 (M15), respectively. In general, setting periods of SAPS series cements were longer than

OPC with a generally higher normal consistency which indicates slower hydration and hardening in a more progressive way especially at a higher concentration of SAPS.

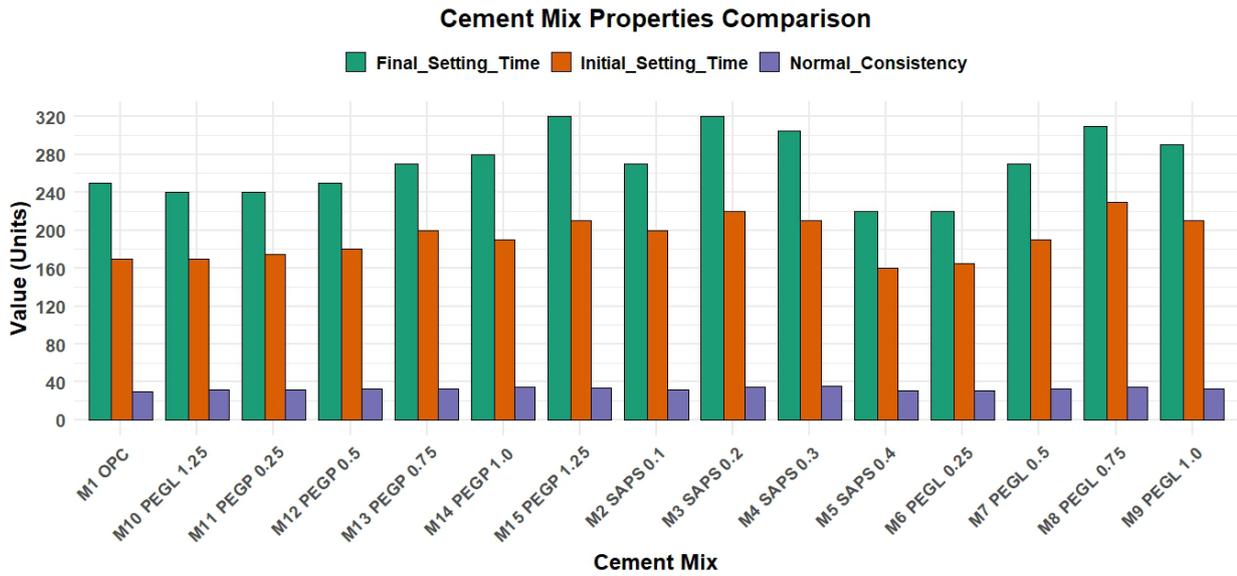


Fig. 1 Cement mix properties

Setting times and consistency of the PEGP series cements are somewhat variable but there is a general tendency for longer setting times for the cements as the percentage of PEG increases. Setting periods of the beginning and the ultimate setting of PEGP series cements range rather steadily, longer times are noted at higher PEGP concentrations.

3.2 Chemical Composition of Materials

The main differences, compared to OPC, are the higher concentrations of SiO₂, Al₂O₃, and Fe₂O₃ in the chemical composition of PPC. These amendments probably result from the presence of pozzolanic elements-which could enhance the properties of long-term strength and chemical resistance-such as fly ash in PPC. Its lesser CaO content may be one reason why PPC does not develop strength as rapidly as OPC. Because OPC has increased CaO content, it is ordinarily used in fast-track building projects or whenever early strength development is required. It has a lower LOI, too, which means less volatiles or contaminants, probably leading to better performance control. Higher availabilities of SO₃ and Al₂O₃ in PPC may influence its setting rate or vulnerability towards temperature variation during hydration. Finally, the superior durability and chemical resistance characteristics may make the PPC offer superior performance for a longer period of time, while OPC is more suited for those applications where early strength is required.

Table 1 Chemical composition of materials

Materials	Chemical Composition in %								
	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	K ₂ O	Na ₂ O	SO ₃	LOI
OPC	21.41	5.54	4.47	62.32	1.23	0	0	2.83	1.05
PPC	35.2	27.4	6.83	19.2	1.73	0	0	4.21	2.74

3.3 Workability of Cement Mortar Analysis

In this case, the water-to-binder ratio for OPC is 0.51 and that of PPC is 0.50. Under such conditions, both the cement types have a similar fresh workability since these values are consistent and also meet IS1727: 1984. With the increase in the amount of SAPS added, the water-to-binder ratio increases accordingly. For example, SAPS 0.4 (M5) has the highest water-to-binder ratio, amounting to 0.56, indicating that the mix retains more water. However, all the mixes conformed to the recommendations of IS1727:1984 despite the higher water-to-binder ratio, which is indicative of the fact that SAPS-treated mortars retain workability within a reasonable range [19].

Water-to-binder ratios in the PEGL series vary between 0.54 and 0.57. While supporting a relatively high water-to-binder ratio of 0.57, higher PEGL concentration, as in PEGL 1.25 (M10), nonetheless meets IS1727:1984 at 0.54. The improved flow behavior of the PEGL-modified mortars is probably due to the superior water retention qualities of PEGL, promoting self-curing. The PEGP series Polyethylene Glycol Polymer also behaves similarly, with an increase in the water-to-binder ratio marginally increasing with an increase in polymer content. With the highest score of 0.57, PEGP 1.25 demonstrates more workability. Therefore, all mixes in this series satisfy the requirements as per IS1727:1984 to establish the fact that PEGP acts effectively to retain the flow of mortar without affecting the limits of acceptability.

Both SAPS and PEGL/PEGP additives enhance the mortar's capacity to retain water, a critical feature for its self-curing properties. SAPS-modified mortars present an improved flow behavior when the binder ratio is lower, suggesting a potentially better hydration control, especially in situations where external curing is limited. The flow ratios of mortars treated with PEGL and PEGP are about 0.55-0.57, considerably higher than the rest. It seems from this that additions of polyethylene glycol improve workability but at some loss in early strength if binder level is not appropriately controlled. Whatever the additive, all the mortars meet the requirements of water to binder ratio as per IS1727: 1984, which implies that the utilization of self-curing agents like SAPS, PEGL and PEGP doesn't impair workability within acceptable limits. This is fundamental since it ensures that fresh mortar is usable without sacrificing the long-term performance properties of the hardened mortar [19].

3.4 Compressive Strength Analysis of OPC Mortar

Mortars of different compositions with OPC as base material and its replacements by superabsorbent polymers (SAPS) and polyethylene glycols in liquid and powder forms, respectively, were tested for compressive strength as a function of time. Mixtures tested at 1, 3, 7, 14, 28, and 56 days of age under air and water curing are shown in Figure 2.

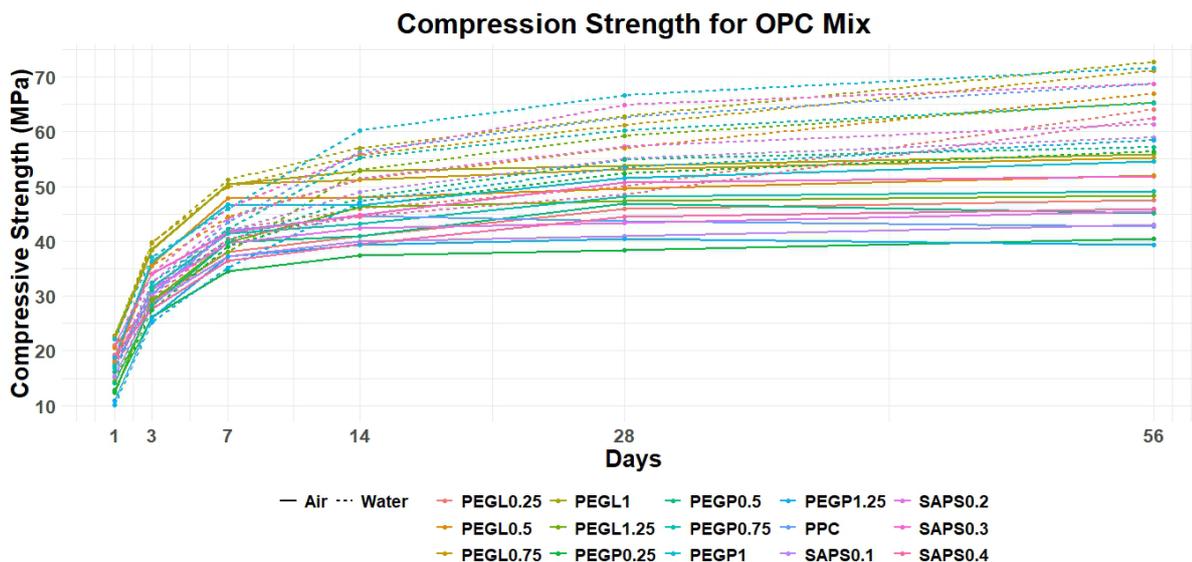


Fig. 2 Compression strength for OPC mix

Conventional OPC mortar was used as a reference to compare various modification performances. Its compressive strength increased from 19.3 MPa at 1 day up to 47 MPa at 14 days and slightly decreased up to 45 MPa at 56 days in the case of air curing, while water curing provided much better strength development, reaching its peak at 71 MPa at 56 days, showing that water curing ensures superiority in strengthening OPC-based mortars.

Modifications with SAPS, PEGL, and PEGP showed different trends as to compressive strength depending on the concentration. SAPS at 0.3% had the best result in SAPS-modified mortars, and it showed a compressive strength of 49 MPa in the case of air curing and 66 MPa in the case of water curing up to 56 days. Among the PEGL-modified mortars, the best performance was exhibited at the concentration of 1.0%, which has matched conventional OPC with 71 MPa at 56 days under water curing. PEGP showed similar tendencies as those of PEGL, the 1.0% gave a compressive strength of 67 MPa under water curing. Beyond 1.0%, added concentrations of both PEGL and PEGP had diminishing returns most probably due to reduction of density within the matrix [20].

In other words, this present study indicates that the improvements in compressive strength vary with each individual additive, and optimum concentration levels are critical to maximum benefits. For example, SAPS fared best at 0.3%, PEGL at 1.0%, and PEGP at 1.0% offered the best balance for strength and durability. Further, water curing provided constant higher strengths for all mixtures compared to air curing, and again proved that curing methods are very critical for reaping the maximum compressive strength of modified OPC mortar.

3.5 Compressive Strength of PPC Mortar Analysis

The compressive strength for OPC modified with different replacements, such as SAPS and polyethylene glycols in liquid and powder forms, respectively, shows interesting trends not only with time but also with the difference in curing conditions. The conventional OPC mortar, which was used for control, showed a progressive rise in strength when water-cured, reaching up to 71 MPa by 56 days, which should relate to the availability of moisture during its curing as shown in figure 3. In contrast, air curing exhibited a plateaued strength gain after 14 days, with only marginal reduction from the peak obtained, probably because of lower hydration and refinement of the microstructure upon termination of moisture supply (CT-OPC) CT-OPC) CT-PPC).

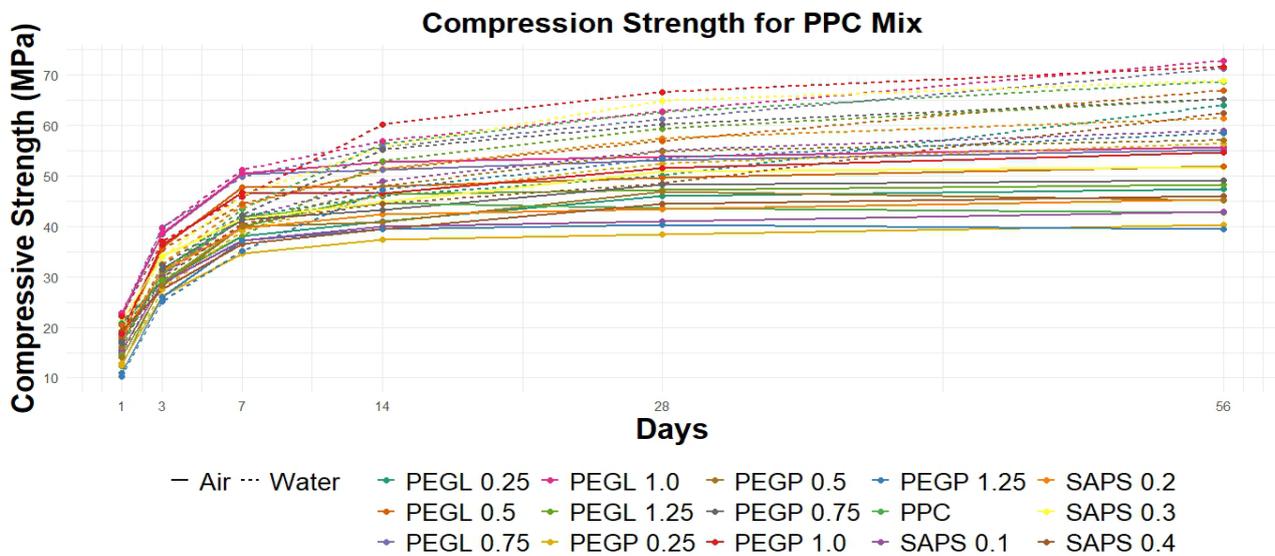


Fig. 3 Compression strength for PPC mix

Data shows that in SAPS-modified mortars, the optimum concentration of SAPS lies in the medium concentration range, such as 0.3%, to achieve proper hydration management and provide structural integrity. While the low concentration of 0.1-0.2% SAPS resulted in lower compressive strengths compared to conventional OPC, the addition of 0.3% SAPS demonstrated comparable or even superior results to 66 MPa under water curing by 56 days. With an increase in the concentration of SAPS to 0.4%, there was a remarkable loss in strength, probably as a result of high water absorption that can destroy the pore structure of mortar and lower the density (CT-OPC) CT-OPC) CT-PPC [21].

Addition of PEGL additives demonstrated that the optimum compressive strength was at 1.0%, with water curing, which matched the maximum strength reached by ordinary OPC of 71 MPa at 56 days. Lower dosages of 0.25 to 0.75% still resulted in relatively significant strength gains and make PEGL a somewhat versatile additive. Conversely, at excessive dosages, 1.25% resulted in reduced strength development, which may show a threshold beyond which PEGL can damage the integrity of the cement matrix due to increased porosity or delayed hydration reactions (CT-OPC)(CT-OPC)(CT-PPC).

PEGP acted similarly to PEGL, arriving at an optimum at approximately 1.0%. For this dosage rate, the PEGP-modified mortars indicated substantial gains in strengths under water curing, to 67 MPa by 56 days. Similar to

SAPS and PEGL, however, beyond the optimum threshold, increased concentrations of this additive were associated with reduced strengths and highlighted the importance of careful calibration of additive amounts to avoid microstructural weakening. Generally speaking, the data all indicate that SAPS, PEGL, and PEGP have a great potential in improving OPC properties if their optimum ranges of concentration are met under appropriate curing conditions CT-OPC.

3.6 Optimum OPC Mortar Compressive Strength Analysis

Compressive strength results for OPC modified with the optimum concentrations of SAPS, PEGL and PEGP of 0.3%, 1.0% and 1.0%, respectively, will provide a clear comparison of how such additives influence mortar properties. These modifications were evaluated at 1, 3, 7, 14, 28 and 56 days under air and water curing conditions are shown in figure 4. These results indicate that each additive was quite effective at some optimum dosage level, which always proved its role in enhancing the compressive strength of OPC-based mortars.

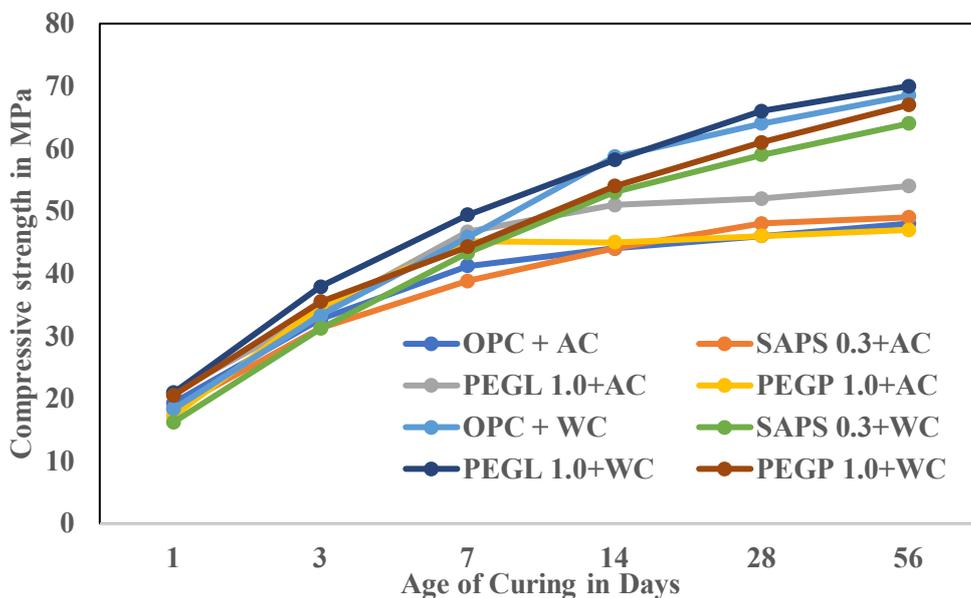


Fig. 4 OPC optimum compressive strength

SAPS at 0.3%, PEGL at 1.0%, and PEGP at 1.0% showed significantly improved compressive strength compared to the control OPC, especially when water curing was applied. For example, SAPS 0.3% attained up to 56 days with water curing, with strengths of about 66 MPa, demonstrating that its water-retaining properties favor progressive strength development, though optimal results require consistent moisture. The condition of PEGL 1.0% was the most uniform and equaled the peak of conventional OPC at 71 MPa under water curing, maintaining robust strength under air curing, likely because of plasticizing effects induced by it. PEGP 1.0% reached a solid 67 MPa with water curing, performing somewhat below OPC, and emphasized that the development of long-term strength requires sufficient moisture. These findings therefore serve to suggest possible ways of taking advantage of SAPS, PEGL, and PEGP in improving mortar performance, especially when adequate curing methods are applied.

On the whole, the optimum replacements of SAPS, PEGL, and PEGP evidenced that these admixtures at appropriate substituting dosages could significantly enhance the mechanical properties of OPC mortar. Water curing continuously yields higher strength gains from all mixtures, underlining the contribution of moisture to developing maximum hydration and structural integrity. The result of the comparative analysis is that although each additive has different properties, their respective optimal concentrations can be close to or, in some cases, equal in performance to conventional OPC, hence promising alternatives for application with some specialization in construction (CT-OPC) (CT-OPC) (CT-PPC).

3.7 Optimum PPC Mortar Compressive Strength Analysis

Compressive strength data for PPC mortar indicates that modified mixtures outperform conventional PPC in terms of not only strength development but more specifically early-age, 1 to 7 days, strength development. Additions of

SAPS at 0.3% and PEGL at 1.0% give better early performance because of accelerated hydration. The highest early strength is developed by PEGL-modified PPC, especially air-cured are shown in figure 5. Generally, water curing has resulted in strength gain for all mixtures from their air-cured strengths. The conventional PPC had a significant strength gain from 49.7 MPa to 68.7 MPa at day 56 under water curing. PEGL-modified PPC also gave the highest overall strength of 72.8 MPa under water curing, illustrating the benefits of improved curing conditions.

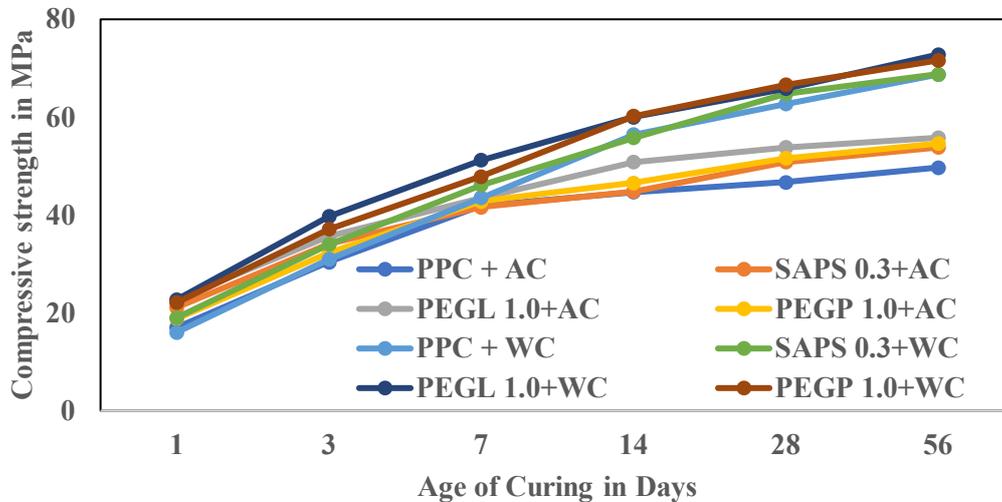


Fig. 5 PPC optimum compressive strength

Long-term trends, on the other hand, vary from 14 to 56 days and indicate that the PEGL-modified PPC maintains its superiority, sustaining the strength gains over time. On the contrary, SAPS-modified PPC exerts quite moderate improvement in such an aspect of performing excellently early on but tapering off in long-term strength development compared with others. PEGP 1.0% provides balanced strength development; hence, it has a place where performance needs to be consistent. Each additive adds its peculiar impact, which underlines that PEGL is most effective for early and long-term strength, SAPS for the early strength gain, whereas PEGP provides a stable option in both early and later stages [22].

Because of their impacts on hydration and moisture retention, air curing and water curing have rather different effects on the characteristics of mortar. In addition to creating a solid, impermeable surface that is resistant to environmental damage, water curing supplies enough moisture for full hydration, increasing strength, durability, and reducing shrinkage and cracking. Air curing, on the other hand, enables mortar to dry quickly, which results in inadequate hydration, decreased strength, greater shrinkage, and a porous structure that is more vulnerable to surface dusting, cracking, and less resistance to weathering and carbonation. Air curing is more convenient but degrades quality over time, while water curing uses more resources but guarantees better performance. Large volumes of water are needed for traditional water curing techniques. Water is a vital resource in areas with limited water supplies, and self-curing mortars reduce or do away with the need for external water curing. Self-curing mortars are a useful invention for environmentally friendly building since they promote sustainability by preserving water, lowering energy requirements, minimizing waste, and increasing the longevity of constructions.

4. Conclusion

This paper epitomizes how additives such as SAPs and PEGL and PEGP can provide improved performance in mortars, especially with optimum curing conditions. Quantitatively, in all the studied mixtures, air curing gives similar compressive strength considering with water curing since air curing is also gives better performance as required. For instance, in conventional OPC mortar, the compressive strength increases to 71 MPa under water curing at 56 days, well above the 45 MPa obtained under air curing conditions.

From this flow values, self-curing mortars rely on an increased water/binder ratio to compensate for the lack of external curing. Therefore, self-curing mortars possess higher water/binder ratios compared to conventional mortars. On the other hand, self-curing mortar mixtures give excellent workability based on flow table data. It is of great importance to ensure proper compaction and surface finish in practical applications.

In terms of additive performance, the 0.3% SAPS-modified mortars reach a strength of 66 MPa after 56 days of water curing, representing a significant percentage gain compared with the two previous lower concentrations.

The PEGL-modified mortars reach an optimum strength of 71 MPa under water curing at 1.0%, comparable to conventional OPC. At the same concentration, PEGP reaches an optimum of 67 MPa under similar conditions and thus proves its efficiency in terms of water retention and strengthening. Relatively speaking, the PPC mortar modified with 1.0% PEGL developed the highest recorded strength of 72.8 MPa under water curing up to 56 days, which has shown that the additive type of PEGL accelerates early-age strength development without sacrificing some of its effectiveness toward its long-term gain in applications where consistency in properties gained over a period of time is desirable. Among others, SAPS, PEGL, and PEGP have shown the capability to improve sustainability and durability in cement-based mortars, provided the optimal concentration is used. These results confirm the effectiveness of an adequate curing method in the complete exploitation of the benefits coming from the investigated additives, since air curing is always guaranteeing better performance like water curing.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

K Jayasankar: Methodology, formal analysis, investigation, resources, writing – original draft, visualization; L Krishnaraj: Data curation, writing – review & editing; P T Ravichandran: Conceptualization, data curation, writing – review & editing, supervision.

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