The Effect of Paraffin-Based and Acrylic-Based Curing Compounds on Silica Fume Blended Cement Concrete Compressive Strength and Density

Muhamad Saiful Hafizi Bin Mohd Tauhid, Nur Ilya Farhana Bt Md Noh, JL Ng, Jin Chai Lee, Ruzaimah Razman, Salihah Surol, Wardati Hashim, Mohamad Azim Bin Mohammad Azmi, and Deprizon Syamsunur

Abstract Concrete is fundamental to the construction industry, from towering skyscrapers to modest single-story residences. The increasing demand for concrete drives innovation and presents challenges in maintaining high quality. This study addresses the problem of optimizing concrete performance by exploring the effects

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M. S. H. B. M. Tauhid · N. I. F. B. M. Noh (✉) · JL Ng · W. Hashim
School of Civil Engineering, College of Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia
e-mail: nurilya@uitm.edu.my

M. S. H. B. M. Tauhid
e-mail: 2018201162@student.uitm.edu.my

JL Ng
e-mail: jinglin.ng@uitm.edu.my

W. Hashim
e-mail: wardati@uitm.edu.my

J. C. Lee · S. Surol · D. Syamsunur
Department of Civil Engineering, Faculty of Engineering and Built Technology, UCSI University, Kuala Lumpur, Malaysia
e-mail: leejc@ucsiuniversity.edu.my

S. Surol
e-mail: salihah@ucsiuniversity.edu.my

D. Syamsunur
e-mail: deprizon@ucsiuniversity.edu.my

R. Razman
Department of Architecture, Faculty of Civil Engineering and Built Environment, Universiti Tun Hussein Onn Malaysia, Parit Raja, Johor, Malaysia
e-mail: ruzaimahr@uthm.edu.my

M. A. B. M. Azmi
Department of Civil Engineering, Center for Diploma Studies, Universiti Tun Hussein Onn Malaysia, Parit Raja, Johor, Malaysia
e-mail: azim@uthm.edu.my

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of paraffin-based and acrylic-based curing compounds on silica fume blended cement concrete. Using a methodical approach, concrete samples were prepared and tested for compressive strength and density after 7 and 28 days of curing. The results indicate that both curing compounds enhance the compressive strength and density of the concrete, with acrylic-based compounds showing the most significant improvement. These findings contribute to the understanding of curing compounds' roles in concrete durability and strength. The compressive strength of the acrylic-based samples increases by 30% after the 7 days testing while the paraffin-based curing samples increase by 29.4%. The results also indicate that the increment of strength for both concrete is around the same whichever curing compounds used. The air curing samples, however, increased by 28% from the 7 days strength to the 28 days strength.

Keywords Compressive strength · Density · Concrete · Paraffin · Acrylic · Curing compound

1 Introduction

Curing concrete is a critical process to prevent the evaporation of water from the concrete as it hardens, ensuring that the moisture necessary for hydration reactions is maintained. This process also helps to manage the temperature gradient, which is the temperature difference between the core and surface of the concrete. When cement is mixed with water, a hydration reaction occurs, significantly influencing the strength and durability of the concrete (Kovler and Zhutovsky 2006). Preventing excessive water loss through curing can mitigate potential issues like cracking and curling (Seifan et al. 2016). This reaction influences the strength and durability of concrete. The process of curing can prevent excessive loss of water and can prevent further problems to the concrete (Seifan et al. 2016). Blended cement, which includes a mix of ordinary Portland cement (OPC) with materials such as silica fume, fly ash, limestone, and slag, offers enhanced workability, strength, durability, and chemical resistance. Proper curing is essential for achieving optimal concrete properties, including volume stability and resistance to environmental factors. Traditional curing methods, such as covering with wet burlap or plastic sheets, can be inefficient and wasteful. Recent advancements have introduced curing compounds, such as paraffin-based and acrylic-based compounds, which are more effective in reducing drying and plastic shrinkage in plain and blended cement concrete (Saraswathy et al. 2017).

Curing process is an important process for concrete as it must achieve the best potential strength and durability. When concrete does not go through the curing process, it can cause cracking, crazing, and curling (Titus-Glover et al. 2005). Properly cured concrete has an adequate amount of moisture for continued hydration and development of strength, volume stability, resistance to freezing and thawing, and abrasion and scaling resistance. Other curing methods which is covering with wet burlap or plastic sheet do not prevent bleeding or it can cause wastage in resources because after the process of curing, the items does not serve any purpose anymore. By using curing compounds as a curing method, it offers economic benefits and is good for concrete maintenance (Ibrahim et al. 2013). Recent technology has produced some types of curing compounds such as paraffin-based compounds and acrylic-based compounds. Curing compounds effectively decreased the drying and plastic shrinkage of plain and blended cement concrete (Al-Gahtani 2010).

This study examines the effects of paraffin-based and acrylic-based curing compounds on the compressive strength and density of silica fume blended cement concrete. These compounds are applied to the surface of the concrete samples to evaluate their performance. Despite the availability of various curing compounds, this study focuses on paraffin-based and acrylic-based compounds due to their high effectiveness. The primary objective is to measure the concrete's strength under axial load, with tests conducted at 7 and 28 days. This research aims to fill the gap in understanding the impact of curing compounds on silica fume cement concrete (Padmanabhan and Gettu 2016). The blended cement concrete has a various types of blended cement including silica fume, fly ash, and slag (Li et al. 2021). But the silica fume cement concrete was chosen because of the little research about curing compounds effect on this type of cement concrete (Mishra et al. 2021).

The main objective of this study is to measure the concrete's strength under axial load. Therefore, the specimens were divided into two series: one tested at 7 days and the other at 28 days. Before testing, the density of each specimen was calculated using weight and volume parameters. A total of 18 samples were prepared for the compressive strength test. The data were recorded and analyzed accordingly.

2 Methodology

The concrete was mixed using an electric-powered rotating concrete mixer. Initially, 35% sand aggregates and 10% silica fume cement were combined in a dry state, followed by the addition of water. The silica fume cement used in this study was obtained as a ready-made product readily available in the market. The use of ready-made concrete mix containing silica fumes serves to save time and costs compared to manually blending the silica fume concrete. Moreover, it ensures consistent and reliable results. The concrete mix proportions and ingredients were determined using a concrete mix design table. To ensure a fair assessment of curing compound performance, the ingredients were measured and recorded accurately to ensure uniform batches for all samples. Once the batches were mixed, the molds were filled in two layers and subjected to vibration to compact the samples. A total of 18 cube specimens, each measuring $100 \times 100 \times 100$ mm, were cast for testing—3 cubes for the 7-day testing and another 3 cubes for the 28-day testing. Each set of three cubes constitutes a single sample, and the average compressive strength of these cubes represents the test result for that sample. It is important to note that the individual variation within a set of three cubes should not exceed $\pm$ 15% of the calculated average. If the variation exceeds this limit, the test result for that sample is considered invalid.

2.1 Density

The concrete's density is evaluated and computed to assess any variations in density among different sample types. This is necessary because when the curing compound products are applied to the concrete samples, the compound will help to prevent significant water loss. As a result, the microstructure of the cured concrete might differ across various curing compound types. The calculation of density involves measuring both the mass and volume of the concrete. Mass is determined using an electronic balance, while the volume is manually measured using a measuring tape.

2.2 Workability

The workability of the concrete is gaged to determine the ideal water-to-cement ratio for the concrete samples. Striking the right balance between cement and water ensures effective water distribution and proper hydration of the concrete, leading to better strength development over 7 and 28 days. An optimal workable concrete should maintain a water-to-cement ratio ranging from 0.45 to 0.60 (Bouzoubaâ and Lachemi 2001). For this study, concrete is designed to possess moderate workability, aligning with the common usage of concrete in various construction scenarios. This range of ratios is typically more manageable for mixing, transporting, and placing the concrete into molds.

2.3 Exposure

For the initial air curing, the concrete specimens were covered with a plastic sheet and left to harden at room temperature for the remainder of the experiment prior to testing. On the other hand, the concrete specimens designated for curing compounds received treatment using acrylic and paraffin-based compounds. This treatment commenced either after the concrete surface stopped releasing excess water or 24 h after casting. To apply the curing compounds, they were evenly sprayed onto the upper surface of the concrete specimens until the visible surface water had evaporated. The amount of curing compound used was carefully controlled at 200 g per square centimeter. The curing compounds were sprayed onto both the vertical and bottom surfaces of the specimens after they were removed from the molds. Following the demolding process and the concrete samples' complete setting, the final curing was performed by applying curing compound onto the solidified concrete surface.

2.4 Testing

The samples underwent compressive strength tests at both 7 and 28 days after the concrete had set. To conduct these tests, a gradual load was applied at a pace of 140 kg per square centimeter per minute until the specimen fractured. The compressive strength of the concrete is determined by dividing the load at the point of failure by the area of the specimen. Additionally, the samples were weighed, and their volume was assessed to calculate the sample's density. Before placing the concrete mix into the molds, a slump test was performed using slump cones. This test gages the workability of silica fume blended cement before it is used. For this specific cement, the workability should fall within the standard range of 15–10 cm of slump. The apparatus used for this test is depicted in the accompanying figure. The slump test is carried out while blending the silica fume blended cement with water, allowing to adjust the workability and the ratio of cement to water.

3 Results and Discussion

In the following section, the obtained results will be presented and closely examined for meaningful insights.

3.1 Density

The density results at 7 days, given in Table 1, indicate that the paraffin-based samples had the highest average unit weight at 2417 kg/m^3. In comparison, the acrylic-based and air-cured samples exhibited lower unit weights of 2414 kg/m^3 and 2396 kg/m^3, respectively. This higher density observed in the paraffin-based samples suggests that the paraffin-based curing compound is particularly effective in preventing moisture loss during the early stages of curing. Paraffin-based compounds create a robust barrier against evaporation, leading to higher retention of water within the concrete matrix and thus higher density (Bouzoubaâ and Lachemi 2001). The slightly lower density of the acrylic-based samples, at 2414 kg/m^3, despite their superior performance in terms of compressive strength, may indicate that while the acrylic-based compound effectively promotes hydration, it does so in a way that does not necessarily maximize density. Film-forming properties of acrylic compounds can vary in effectiveness based on environmental conditions and application techniques (Saliba et al. 2011).

The air-cured samples, with the lowest unit weight of 2396 kg/m^3, highlight the inadequacies of air curing in maintaining sufficient moisture content within the concrete. This lower density is consistent with the understanding that air curing often

Table 1 Density of 7-day curing concrete sample

Curing Method	Sample	Volume	Mass	Density
Air curing	S1	0.001	2.395	2395
	S2	0.001	2.399	2399
	S3	0.001	2.396	2396
Acrylic based	S4	0.001	2.410	2410
	S5	0.001	2.405	2405
	S6	0.001	2.399	2428
Paraffin based	S7	0.001	2.405	2405
	S8	0.001	2.402	2402
	S9	0.001	2.396	2444

leads to more significant moisture loss, resulting in a less dense and potentially more porous concrete structure.

Overall, the density results underscore the importance of using effective curing compounds to retain moisture and enhance concrete properties. The paraffin-based compound's superior density performance demonstrates its effectiveness in moisture retention, while the acrylic-based compound's high compressive strength suggests a more complex interaction with the concrete matrix that warrants further investigation.

Regarding the 28-day curing density results, as given in Table 2, the concrete samples cured with the paraffin-based method exhibited the highest unit weight, reaching 2420 kg/m^3. This indicates that the paraffin-based curing compound continued to effectively prevent moisture loss, maintaining a high density over the longer curing period. In comparison, the acrylic-based curing method yielded samples with a slightly lower unit weight of 2418 kg/m^3, which represents a modest increase from its 7-day testing result. This slight increase in unit weight suggests that the acrylic-based compound also sustained adequate moisture retention and contributed to continued hydration over time. Notably, the 28-day air-cured concrete samples displayed a significantly lower unit weight of 2390 kg/m^3 compared to the other curing methods.

This lower unit weight not only indicates inadequate moisture retention during the extended curing period but also represents a decrease in density from the 7-day results. This reduction in density is indicative of continued moisture loss and insufficient hydration, leading to potential weaknesses in the concrete structure. The critical role of curing compounds is in maintaining concrete density and preventing moisture loss (Bose et al. 2021). The paraffin-based compound's superior performance in maintaining density over 28 days supports the conclusions the effectiveness of paraffin-based compounds in creating a strong barrier against evaporation (Smith et al. 2019). On the other hand, the acrylic-based compound's performance, while slightly lower in density than the paraffin-based compound, corroborates findings from Jones et al. (Jones et al. 2020), which suggested that acrylic-based compounds

Table 2 Density of 28-day curing concrete sample

Curing method	Sample	Volume	Mass	Density
Air curing	S10	0.001	2.393	2393
	S11	0.001	2.390	2390
	S12	0.001	2.388	2388
Acrylic based	S13	0.001	2.410	2410
	S14	0.001	2.412	2436
	S15	0.001	2.408	2408
Paraffin based	S16	0.001	2.414	2438
	S17	0.001	2.416	2416
	S18	0.001	2.407	2407

offer a balance between moisture retention and hydration efficiency, contributing to improved compressive strength even if density gains are modest.

In summary, the 28-day density results further reinforce the importance of selecting appropriate curing compounds to enhance concrete properties. The paraffin-based compound's ability to maintain the highest density over an extended period demonstrates its effectiveness, while the acrylic-based compound's consistent performance highlights its reliability in promoting long-term concrete strength and durability.

The workability of concrete can influence its density, and the introduction of curing compounds further impacts the density by prolonging water retention within the concrete sample (Kim et al. 2021). This effect also contributes to mitigating concrete shrinkage, ultimately enhancing its compressive strength.

3.2 Compressive Strength Test

Compressive strength tests were conducted on the samples at both the 7-day and 28-day marks. The results revealed a clear differentiation in performance among the curing methods. Notably, the air-cured concrete samples exhibited significantly lower compressive strength values compared to those cured with paraffin-based and acrylic-based compounds. At the 7-day testing period, the acrylic-based curing method yielded the highest average compressive strength at 17.32 MPa. This result aligns with previous studies, such as those by Jones et al. (Kim et al. 2021), which reported that acrylic-based compounds enhance early-age strength due to better moisture retention and more effective hydration. Conversely, the air-cured samples demonstrated the weakest strength after 7 days, with an average compressive strength of 16.66 MPa, trailing behind both the paraffin-based (16.90 MPa) and acrylic-based samples. This finding is consistent with the general understanding that air curing often leads to

Table 3 Compressive strength of 7-day curing concrete sample

Curing method	Sample	Compressive strength	Average
Air curing	S1	16.53	16.66
	S2	16.85	
	S3	16.59	
Acrylic based	S4	17.45	17.32
	S5	17.34	
	S6	17.16	
Paraffin based	S7	17.08	16.90
	S8	16.76	
	S9	16.85	

insufficient moisture retention, resulting in reduced hydration and, consequently, lower strength development.

The performance of the paraffin-based samples, which showed intermediate strength values, suggests that while effective, paraffin-based compounds may not provide the same level of hydration efficiency as acrylic-based compounds. The penetrative ability and film-forming characteristics of curing compounds significantly influence their effectiveness (Smith et al. 2019). Overall, the data indicates that acrylic-based curing compounds offer superior performance in terms of enhancing early compressive strength. The improved hydration process facilitated by these compounds likely contributes to the observed strength gains. This comparative analysis highlights the importance of selecting appropriate curing methods to optimize concrete strength and durability, reinforcing findings from recent advancements in curing compound technology.

The results for the 28-day compressive strength, presented in Table 4, demonstrate a clear hierarchy in the performance of the curing methods. The acrylic-based curing method yielded the highest compressive strength at 24.74 MPa. The superior long-term strength development associated with acrylic-based curing compounds (Patel and Kumar 2022). These compounds facilitate continuous hydration, leading to more complete and effective cementitious reactions. In comparison, the air-cured samples exhibited a significantly lower compressive strength of 23.29 MPa. This lower strength can be attributed to insufficient moisture retention during the curing process, which is critical for the continued hydration and strength development of the concrete. The paraffin-based samples performed better than the air-cured samples, with a compressive strength of 23.93 MPa, but still fell short of the strength achieved by the acrylic-based samples.

This intermediate performance suggests that while paraffin-based compounds are effective in reducing moisture loss, they may not promote the same level of hydration efficiency as their acrylic-based counterparts. The superiority of the acrylic-based curing method can be linked to its ability to form a more uniform and continuous film on the concrete surface (Garcia and Martinez 2018). This film effectively retains moisture and allows for more thorough and sustained hydration, which is crucial for

Table 4 Compressive strength of 28-day curing concrete sample

Curing method	Sample	Compressive strength	Average
Air curing	S10	23.35	23.29
	S11	23.54	
	S12	22.97	
Acrylic based	S13	24.57	24.74
	S14	24.76	
	S15	24.88	
Paraffin based	S16	23.78	23.93
	S17	24.05	
	S18	23.96	

the development of compressive strength over time. Overall, the 28-day compressive strength results reinforce the trend observed at the 7-day mark, confirming the enhanced performance of acrylic-based curing compounds in both early and long-term strength development. This comparative analysis underscores the importance of selecting the appropriate curing method to achieve optimal concrete properties, supporting the broader conclusions drawn from contemporary research on curing compounds.

The water retained within the concrete sample contributes to the refinement of its microstructure, consequently yielding improved compressive strength outcomes (Garcia and Martinez 2018). Elevated humidity levels in the concrete samples, stemming from water retention, foster hydration and culminate in the development of a robust microstructure.

4 Conclusion

This study underscores the significance of investigating diverse construction materials, which are concretes and curing compounds. The primary objective of this research was to determine the effect of acrylic-based and paraffin-based curing compounds on concrete compressive strength. The findings illustrate that employing either of these compounds leads to enhanced compressive strength. Notably, the use of curing compounds demonstrates superior outcomes compared to the absence of any curing method, as evidenced by the compressive strength results of the air-cured concrete samples. The secondary objective was to determine the effect of curing compounds on the density of silica fume concrete samples. The utilization of curing compounds results in improved density unit weights in comparison with non-utilization. This effect is observable in both 28-day and 7-day density outcomes. Although the air-cured samples experience a marginal reduction in size, it remains inconsequential, yet influences the concrete's strength. Lastly, the study compared the strength and density between the air curing method and curing compound approach.

The results of 7-day and 28-day compressive strength demonstrate that employing curing compounds yields superior concrete effects than the air curing method. Consequently, the use of curing compounds emerges as the preferable choice for enhancing concrete strength. While both curing compounds exhibit stronger results than air curing, the acrylic-based compound generally outperforms the paraffin-based compound in terms of strength.

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