

## Fire Protection of Self-Compacted Concrete Using Cement-Perlite-based Coatings

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### ABSTRACT

This study evaluates the effectiveness of cement-perlite-based protective coatings in improving the fire resistance of self-compacting concrete (SCC). Three groups of specimens were exposed to fire: C0 (uncoated specimens), C1 (specimen coated with cement-perlite), and C2 (specimen coated with cement-perlite reinforced with 0.75% glass fiber). The thickness of coating layer is 20 mm for each type. The residual strengths were evaluated relative to 56 days before fire exposure. All specimens exposed to a temperature of (600 C°) with different exposure durations (60, 90, and 120 min). The results indicate that increasing fire exposure duration leads to a high reduction in strength for all specimens. The uncoated specimens exhibited a high decrease in residual compressive strength from 71.43% to 36.35% as the exposure duration increased from 60 to 120 min. In contrast, coated specimens demonstrated substantially higher residual strength. The C1 specimens remained at 92.38%, 84.13%, and 77.78%, while C2 specimens remained at 95.24%, 88.89%, and 81.27% at 60, 90, and 120 min, respectively, while residual strength for splitting tensile and flexural strength followed the same trend with different percentages. The findings confirm that cement-perlite coatings significantly improve the fire resistance of SCC. The novelty of the study lies in the comparative evaluation of plain and glass-fiber-reinforced cement-perlite coatings under various durations of fire exposure. The coating reinforced with glass fibers exhibited the highest protection level and the best ability to preserve the residual mechanical properties of SCC after exposure to fire among the investigated coating layers.

**Keywords:** Fire protective coating, Glass fiber, Lightweight expanded perlite, Self-compacting concrete.

### 1. INTRODUCTION

Okamura first introduce self-compacting concrete (SCC) in 1986 as a highly flowable concrete that can fill the formwork under its own weight without the need of vibration (**Okamura and Ouchi, 2003**). It is distinguished by superior flowability, passing ability, and filling capacity, enabling it to effortlessly flow into formwork and navigate past dense reinforcement. Self-compacting concrete decrease construction duration and labor

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expenses, while its development has been enhanced by including supplemental cementitious elements such as fly ash, silica fume, and other mineral additives (**Abbas et al., 2022; Mathews et al., 2020**). However, when concrete is exposed to fire or high temperature the mechanical characteristics of concrete suffer from significant deterioration, where the high temperature may cause cracking and spalling, which reduce structural integrity, shorten service life, and may expose the reinforcing steel to further damage (**Sahoo et al., 2020**). This issue becomes more critical in SCC, since it is a special kind of concrete that contains mineral and chemical admixtures (**Abd and Abbas, 2025; Kalifa et al., 2000**). The dehydration of the C-S-H gel and the rise in pore water pressure are the primary causes of concrete degradation at high temperatures. The dense microstructure and low permeability of SCC can restrict the movement of moisture and water vapor during fire exposure, leading to the development of internal pressure. This pressure increases the risk of spalling and decreases fire resistance at high temperatures (**Abd and Abbas, 2025; Chan et al., 1999; Sideris, 2007; Ye et al., 2007**). The degree of temperature and the length of time of fire exposure determine the degree of structural damage. Previous studies indicated that SCC can maintain a significant portion of its original strength when exposed to relatively low temperatures. However, the residual strength progressively decreases with increasing temperature and longer fire exposure durations (**Demir et al., 2019; Ilki and Kumbasar, 2002**). The heating rate at the concrete interface, thermal spalling, and the impact of matrix properties like cementitious materials, initial moisture, and aggregate type at high temperatures are key factors influencing the fire performance of SCC (**Khoury, 2008**). These findings give a more accurate scientific basis for assessing fire performance, leading to safer and more conservative outcomes, while supporting the development of new design solutions and the efficient use of thermal barriers and passive fire-protection systems for concrete (**Abdukadir and Ahmed, 2021**).

Perlite is a natural volcanic material that naturally occurs, then is manufactured, crushed, and heated under high temperatures to expand and produce a lightweight porous material (**Bao et al., 2023; Qasim and Fawzi, 2024; Tanhadoust et al., 2023**). Perlite can easily expand when affected by high temperatures, allowing it to become lightweight. It has the capability to provide excellent thermal insulation and fire resistance, making buildings more energy efficient (**Bageri et al., 2021; Pálková et al., 2020**). The mechanism of thermal function of perlite is related to its nature, where it is a naturally occurring material formed when lava cools down very fast and the resulting become hydrated. It contains about 2–5% water, and when exposed to extreme fire temperatures, water-vaporizes, causing the particles to expand by 4–20 times their original volume (**Breese and Barker, 1994**). (**Ealiyas Mathews et al., 2022; Thanaraj et al., 2025**) used cement-perlite-plaster to protect different types of concrete, their findings indicate that cement-perlite plaster reduces fire damage and enhances the fire resistance for prolonged fire exposure.

Although previous studies have shown the effectiveness of cement-perlite-based materials in improving the fire resistance of conventional concrete, little information is available about their application as a protective coating for self-compacting concrete (SCC) reinforced with glass fiber and subjected to different fire-exposure periods. The aim of this study is to evaluate the efficiency of cement-perlite coatings, with and without glass fiber, in retaining the residual mechanical properties of SCC exposed to elevated temperatures. The originality of this research is the comparative assessment of plain and glass-fiber-reinforced cement-perlite coatings subjected to different fire exposure durations and their ability to retain the

residual compressive, splitting tensile and flexural strengths of SCC. **Table 1.** Presents previous studies about fire protective coatings with important key findings.

**Table 1.** Previous studies of fire protective coatings

| No | Fire protective coating                                             | Type of concrete    | Thickness    | Durations                                                  | Key finding                                                                                                                                                                                                                                                                          |
|----|---------------------------------------------------------------------|---------------------|--------------|------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1. | Cement-Perlite plaster<br>(Ealiyas et al., 2022)                    | SCC columns         | 20 mm        | Standard fire curve for 60, 90, 120, and 180 min (ISO 834) | <ul style="list-style-type: none"> <li>• Cement perlite plaster reduces fire damage.</li> <li>• It has strong thermal protection.</li> <li>• Improve long term performance.</li> <li>• Final loss in strength was reduced to about 32-34% after prolonging fire exposure.</li> </ul> |
| 2. | Cement – perlite coating<br>(Thanaraj et al., 2025)                 | Reinforced concrete | 20 mm        | Standard fire curve for 60, 90, and 120 min (ISO 834)      | <ul style="list-style-type: none"> <li>• Cement-perlite coating reduces internal temperature by 62%</li> <li>• Improve loading capacity</li> <li>• Enhance fire resistance.</li> </ul>                                                                                               |
| 3. | Cement perlite plaster<br>(Mathews et al., 2023)                    | SCC                 | 20 mm        | standard fire curve for 30 min (ISO 834)                   | <ul style="list-style-type: none"> <li>• Provide very good fire protection</li> <li>• Improve impact resistance by 80-90%</li> </ul>                                                                                                                                                 |
| 4. | Cement /gypsum-perlite-vermiculite mortar<br>(Caetano et al., 2024) | Normal concrete     | 10 and 20 mm | Standard fire condition                                    | <ul style="list-style-type: none"> <li>• Coatings provide acceptable fire protection</li> <li>• Has good heat insulation</li> <li>• The 20 mm thickness coating gives better fire resistance than 10 mm coating.</li> </ul>                                                          |

## 2. EXPERIMENTAL WORK

### 2.1 Materials

#### 2.1.1 SCC Materials

In this experimental work, eight materials were used to produce self-compacting concrete. **Table 2** shows all the materials used to produce SCC, with their characteristics

**Table 2.** Materials utilized in SCC production.

| Material  | Characteristics                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | Picture                                                                               |
|-----------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|
| 1. Cement | Ordinary Portland cement, type (CEM I-42.5R.) was adopted throughout experimental work. The physical and chemical characteristics of cement in accordance with (IQS No.5, 2019). The Blain fineness reached 305 m <sup>2</sup> /kg, while the autoclave value was 0.47%. Vicat measurements indicated am (initial setting of 85 min) and (final setting of 4.67h). The compressive strengths were 23.2 and 45.7 MPa at 2 and 28 days. Chemically, the binder contained 61.47% CaO, 21.28% SiO <sub>2</sub> , 4.03% Al <sub>2</sub> O <sub>3</sub> , and 3.56% Fe <sub>2</sub> O <sub>3</sub> . The MgO and SO <sub>3</sub> contents remained within the allowable |  |

|                                                 |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                                                                                       |
|-------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|
|                                                 | specification limits of IQS No.5 with values 2.1 and 1.82, subsequently. In addition, the insoluble residue and loss on ignition values were 1.20% and 0.7%, respectively. The main clinker components were (51.13% C <sub>3</sub> S, 22.44% C <sub>2</sub> S, 4.66% C <sub>3</sub> A, and 10.83% C <sub>4</sub> AF).                                                                                                                                                                                                                                                                                                                                 |                                                                                       |
| <b>2. Fine aggregates</b>                       | Natural sand was utilized; The grading and the properties of fine aggregates were examined according to <b>(IQS No.45, 1984)</b> . The grading of sand lies in Zone 2, with passing percentages ranging from 95% at 4.75mm sieve to 7% at 0.15 mm sieve. The F.M was 2.67, indicating suitable grading for SCC. The physical and chemical properties of sand comply with IQS requirements. SO <sub>3</sub> content was 0.36%, while the percentage of fine particles passing the 75 µm sieve reached 3.5%, Clay lumps and friable materials were 0.72%. In addition, the dry rodded density and SG were 1633 kg/m <sup>3</sup> and 2.6, respectively. |    |
| <b>3. Coarse aggregates</b>                     | Natural gravel, with a nominal aggregate size of 10 mm was selected for making SCC. The practical size distribution satisfied the specification of <b>(IQS No.45, 1984)</b> for coarse aggregates within 5-14 mm grading limits. The gravel had acceptable physical and chemical characteristics, including SO <sub>3</sub> content of 0.086%, fine particles passing the 75 µm sieve of 1.05% and clay lumps and friable materials of 1.3%. Moreover, the dry rodded density and SG were 1595 kg/m <sup>3</sup> and 2.65, respectively.                                                                                                              |    |
| <b>4. Silica fume</b>                           | Silica fume was partially replaced by 6% of the cement weight to improve the behavior of SCC mix. The materials conforms to the ASTM specification of <b>(ASTM C 1240, 2020)</b> . The silica fume exhibit SiO <sub>2</sub> content of 93% and specific surface are of 17 m <sup>2</sup> /g. in addition, the pozzolanic activity index reached 116% at 7 days. The loss of ignition and moisture content were 3.15% and 0.34%, respectively. Remaining within the permissible specification limits.                                                                                                                                                  |  |
| <b>5. Limestone</b>                             | Limestone was adopted as a filler material in the mix. The role of limestone is to improve the workability and to prevent the segregation of the mix. The physical and chemical characteristics of limestone are satisfied to the specification of <b>(ASTM C1797, 2023)</b> . The CaO content of 97.95% with minor amounts of Fe <sub>2</sub> O <sub>3</sub> , SiO <sub>2</sub> , ZnO, MgO, and SO <sub>3</sub> and the strength activity index of 85% at 28 days.                                                                                                                                                                                   |  |
| <b>6. Mixing water</b>                          | Tap water was selected in this study, which conformed to <b>(IQS No.1703, 2018)</b> . It was used at all stages of this experimental work, including the mixing and curing processes.                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |  |
| <b>7. Chemical admixture – superplasticizer</b> | High range water reducer (HRWRA), It is a modified polycarboxylate aqueous solution, it is a 3 <sup>rd</sup> generation, Type (E), it is from Sika ViscoCrete -171 Precast with a pH-value of 5-7. The properties of the SP is conform to <b>(ASTM C494, 2024)</b> . It was used to accelerate strength and reduce water content.                                                                                                                                                                                                                                                                                                                     |  |

|                       |                                                                                                                                                                                                                                                          |                                                                                     |
|-----------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|
| <b>8. Glass fiber</b> | Glass fiber Type (E-glass) was incorporated into SCC mix by volume fraction of 1%. It consists of white, short and chopped stands with (L= 12 mm and D=10 $\mu$ m). Glass fiber has a unit weight of 2700 kg/m <sup>3</sup> and Young Modulus of 72 Gpa. |  |
|-----------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|

### 2.1.2 Fire Protective Coating Materials

Two kinds of fire protection coating were used. The first coating consists of cement-perlite, while the second coating comprises cement-perlite reinforced with 0.75% glass fiber by volume fraction of the coating layer. The material attributes are shown in **Table 3**.

**Table 3.** Characteristics of coating materials.

| Materials                              | Characteristics                                                                                                                                                                                                                                                                                                                                                                                                                                              | Picture                                                                               |
|----------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|
| <b>1. Cement</b>                       | The same cement used in the production of SCC.                                                                                                                                                                                                                                                                                                                                                                                                               |   |
| <b>2. Lightweight Expanded Perlite</b> | Perlite has a SG of 2.14 and bulk density of 200 kg/m <sup>3</sup> . The particle size ranged from 0-1 mm according to <b>(Koneř and Mynarz, 2023)</b> . The chemical composition of perlite mainly consisted of 73% SiO <sub>2</sub> and 13% Al <sub>2</sub> O <sub>3</sub> , while Minor components included 1% MgO, 1.5% Fe <sub>2</sub> O <sub>3</sub> , and 0.8% CaO. In addition, Na <sub>2</sub> O and K <sub>2</sub> O were 3% and 4%, respectively. |  |
| <b>3. Water</b>                        | Same water used in the production of SCC.                                                                                                                                                                                                                                                                                                                                                                                                                    |  |
| <b>4. Glass fiber</b>                  | Same glass fiber used in the production of SCC with 0.75% by volume of the coating layer.                                                                                                                                                                                                                                                                                                                                                                    |  |

## 2.2 Mix Design

### 2.2.1 Mix Design, Casting and Curing of SCC

The mixing proportion of the adopted SCC mix is presented in **Table 4**. It was conducted according to **(EFNARC, 2005)** guideline. After completing the mixing process of SCC mix, the



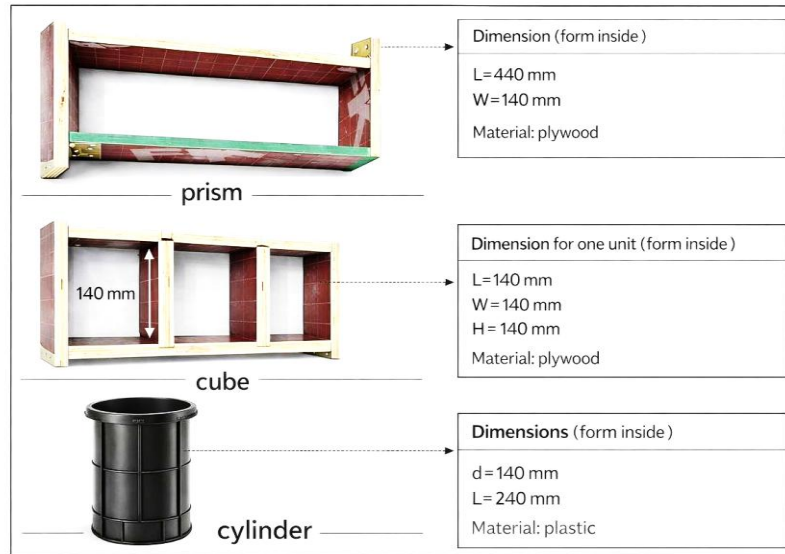
fresh properties were tested, which include (Sump flow,  $T_{500}$ , V-Funnel, L-Box and Sieve Segregation Index). The fresh mix was cast in three types of molds, a cube 100 mm side length for the compressive strength test according to (BS EN 12390-3, 2019), cylinder with (L=200 and D=100) mm for splitting tensile strength test conform (ASTM C496, 2017), and a prism with (400\*100\*100) mm for the flexural strength test, complying with (BS EN 12390-5, 2019). All molds were cleaned and lubricated before pouring the fresh mixes. The Average reading of three tested specimens was taken as the reading for each test. Specimens were cured for 28 days with water, then removed from water and left in a lab environment for another 28 days for air drying according to the work of (Salih and Jasim, 2009).

**Table 4.** Mix proportion to produce 1 m<sup>3</sup> of SCC in (kg/m<sup>3</sup>).

| Cement | Sand | Gravel | Silica fume | Limestone | SP    | Water | Glass fiber | w/p  |
|--------|------|--------|-------------|-----------|-------|-------|-------------|------|
| 510    | 779  | 870.6  | 30.6        | 60        | 18.81 | 156.6 | 27          | 0.29 |

### 2.2.2 Mix Design, Casting and Molding of Fire Protective Coatings

- Mix design of Cement-perlite coating:** it is produced by blending ordinary Portland cement with grounded lightweight expanded perlite in a ratio of (1:4) by volume with 0.6 w/c ratio to obtain a lightweight, thermally insulating coating (Ealiyas et al., 2022; Thanaraj et al., 2025). The dry components, cement, and perlite were first mixed to achieve uniform distribution. Water was then added to form a workable mortar. After mixing, the coating was applied uniformly at a thickness of 20 mm for all specimens to ensure proper comparison for specimens. The physical and strength characteristics of the fresh mortar were then tested to verify the integrity and quality of the coating layer before the fire exposure test. The fresh mixture was prepared and cast into cube specimens with dimensions of (50\*50\*50) mm according to (ASTM C109/C109M, 2023). The density of the mortar was found to be 1500 kg/m<sup>3</sup> and a compressive strength of 24.56 MPa. Because perlite has low thermal conductivity, this kind of coating is employed for insulation and fire prevention.
- Mix design of Cement - perlite reinforced with glass fiber:** A new type of coating created by using the same materials as the first coating, cement: perlite mixed in a ratio of (1:4) by volume with 0.65 w/c ratio, but with the addition of glass fiber were incorporated in the plaster by 0.75% of volume fraction of the mix of the coating layer. The reason for the addition of glass fiber is to prevent any chance of spalling during the burning test and to enhance the cement-perlite coating. The mortar's strength and physical properties were examined. The density was 1570 kg/m<sup>3</sup>, and the compressive strength was 28.72 MPa.
- Molding and casting:** Molds for the fire-protective coatings were fabricated to achieve a uniform thickness of 20 mm for cube, cylinder, and prism specimens. The mold dimensions are illustrated in Fig. 1. After 56 days of curing, specimens were cleaned and roughened to prevent any separation during fire exposure. Then, the specimens were placed inside the molds. After that, fresh coating mixes were applied and left to set for 24 hours under ambient conditions. Fig. 2 displays the steps of casting and molding of fire protective coatings.



**Figure 1.** Details of fabricated molds



**Figure 2.** Molding and casting the fire protective coatings

## 2.3 Testing Program

### 2.3.1 Fresh Characteristics Tests of SCC

Five experiments were carried out to investigate the fresh characteristics of SCC as seen in **Fig. 3**, Flowability was evaluated by the slump flow test, passage ability was examined by the L-box test, viscosity and flowability was assessed by the T<sub>500</sub> mm and V-funnel tests and resistance to segregation was measured by the sieve segregation test. These tests were conducted in compliance with (EFNARC, 2005).



**Figure 3. (A) Slump flow test, (B) L-Box test and (C) V-Funnel test**

### 2.3.2 Hardened Properties of SCC

This section shows details of the hardened properties for the SCC done during the experimental work:

#### 2.3.2.1 Compressive Strength Test

As presented in **Fig. 4** in compliance with **(BS EN 12390-3, 2025)** a cube of (100×100×100) mm was used. Eq. (1) was utilized to get the average strength of three specimens.

$$F_c' = \frac{P}{A} \quad (1)$$

Where:  $F_c'$ : Compressive strength in (MPa),  $P$ : Maximum applied force in (N),  $A$ : Area exposed to force in (mm<sup>2</sup>).



**Figure 4. Compressive strength test set up**

#### 2.3.2.2 Flexural Strength Test

According to **(BS EN 12390-5, 2019)**, prism specimens of (100×100×400) mm, supported by a central point force as demonstrated in **Fig. 5**. Eq. (2) was utilized to get the mean flexural strength of three specimens.

$$R = \frac{3PL}{2bd^2} \quad (2)$$

Where:  $R$ : Flexural strength in (MPa),  $P$ : Maximum applied force in (N),  $L$ : Span length in (mm),  $b$ : Specimen width in (mm),  $d$ : Specimen depth in (mm).



**Figure 5.** Flexural strength test set up

### 2.3.2.3 Splitting Tensile Strength Test

Cylinder specimens were used 100 mm in diameter and 200 mm in height, in accordance with **(ASTM C496/C496M, 2017)**, as can be seen in **Fig. 6**. Eq. (3) is used to calculate the average splitting strength for three specimens.

$$T = \frac{2P}{\pi ld} \quad (3)$$

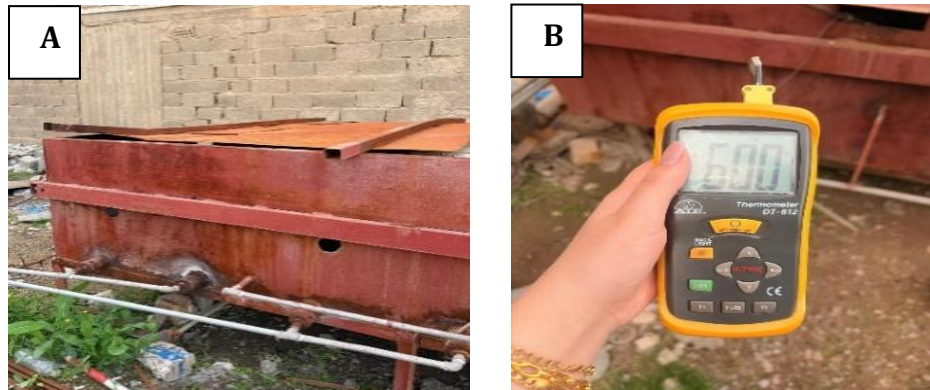
Where: T: Splitting tensile strength in (MPa), P: Maximum applied force in (N), d: Cylinder diameter in (mm), l: Cylinder length in (mm)



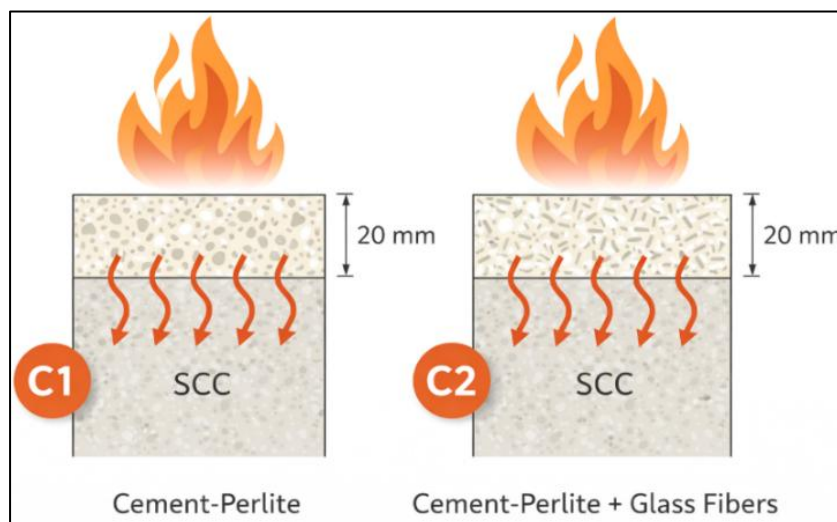
**Figure 6.** Splitting tensile strength test set up

## 2.4 Burning Procedure

Following 28 days of water curing, all specimens were taken out of the water and stored under laboratory conditions for an additional 28 days. This process reduces internal moisture and minimizes vapor pressure during a fire test, which can lead to spalling and cracking **(Salih and Jasim, 2009)**. Then the coated and uncoated specimens were exposed to fire exposure in a steel furnace with dimensions of (3500×2000×900) mm and the furnace temperature was recorded via a digital thermometer, as demonstrated in **Fig. 7**. Specimens were exposed to a temperature of (600 C°), the standard fire curve was followed to reach the required temperature in accordance with **(ASTM E119-00a, 2017)**. The specimens were kept at the required temperature for three specified exposure times of (60, 90, and 120) min. After the fire exposure process, the furnace was ignited, and the specimens were let to cool gradually, preparing them for testing. All protective coatings were removed from the specimens to assess the residual (compressive, splitting and flexural) strengths of the specimens. **Fig. 8** illustrates the fire protection mechanism of SCC using cement-perlite and fiber-reinforced coatings.



**Figure 7. (A) Burning furnace, (B) Digital thermometer**



**Figure 8. Fire Protection mechanism of SCC using cement-perlite and fiber-reinforced coatings (illustrated by Canva)**

### 3. RESULTS AND DISCUSSION

This section assesses the fresh characteristics and fire resistance of SCC, as well as the efficacy of cement-perlite protective coatings. The specimens included uncoated SCC specimens (C0), cement-perlite plaster coated specimens (C1), and cement-perlite plaster reinforced with glass fiber coated specimens (C2). The specimens were subjected to fire at 600 °C for different periods of fire exposure (60, 90 and 120) min and then evaluated to determine their residual mechanical performance post-cooling.

The residual mechanical parameters were evaluated and compared to the reference values at 56 days, which included a compressive strength of 63 MPa, a flexural strength of 9.5 MPa, and a splitting tensile strength of 6.3 MPa. This comparison offers a quantitative evaluation of the deterioration resulting from fire exposure and assesses the

#### 3.1 Fresh Properties

The test results of the fresh properties for SCC are presented in **Table 5**. These tests consisted of (slump flow, T<sub>500</sub>, V-Funnel, L-Box and Sieve segregation index). The presence



of 1% glass fiber into SCC mix significantly reduced workability and affected the rheological behavior of SCC due to the formation of fiber network within the mix. This network may restrict the free movement of the mix, which leads to higher friction and viscosity and lower flowability (**Aboud et al., 2024**).

Furthermore, glass fiber increases the specific surface area of the mix, which requires more paste. Similar observation was noted by (**Hake et al., 2020**) who mentioned that glass fiber affects the flow characteristics of SCC by increasing internal friction, which is why an appropriate dosage of superplasticizer was added to achieve the required workability. All workability parameters satisfied the SCC's standards in accordance with the guidelines of (**EFNARC, 2005**), confirming that the mix has good filling ability, passing ability and segregation resistance for self-compacting concrete application.

**Table 5.** Fresh properties of SCC.

| Mix                                               | Slump Flow (mm)                           | T <sub>500</sub> (sec)     | V-funnel (sec) | L-box  | SI %                 |
|---------------------------------------------------|-------------------------------------------|----------------------------|----------------|--------|----------------------|
| <b>Adopted mix</b>                                | 690                                       | 4.1                        | 12.8           | 0.84   | 15.7                 |
| <b>Limits of EFNARC 2005, acceptance criteria</b> | SF1 550-650<br>SF2 660-750<br>SF3 760-850 | VS1/VF1 ≤ 2<br>VS2/VF2 > 2 | ≤ 8<br>9 to 25 | > 0.80 | SR1 ≤ 20<br>SR2 ≤ 15 |

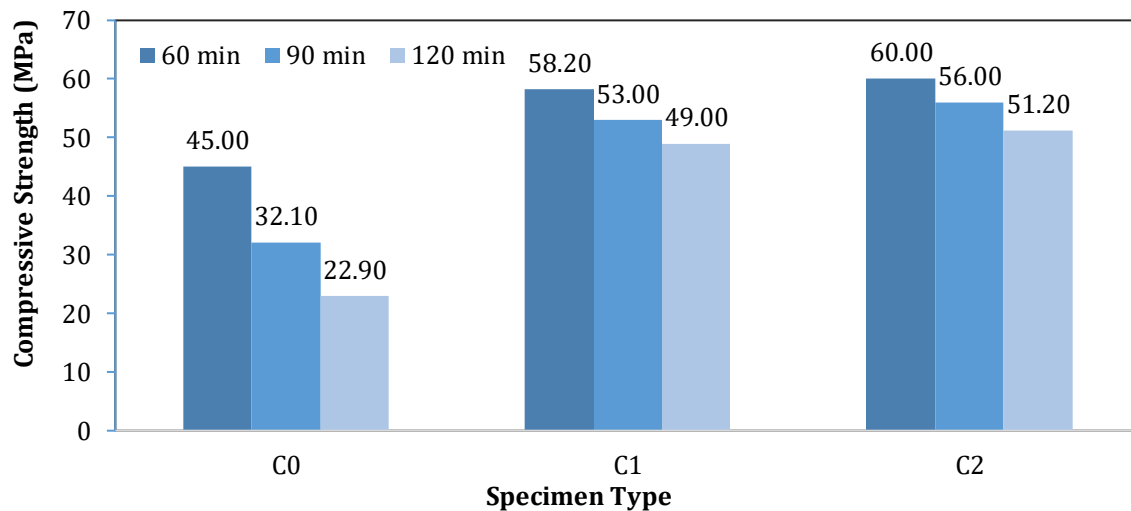
### 3.2 Compressive Strength Performance after Fire Exposure

Compressive strength is considered to be the main parameter to evaluate the mechanical behavior of SCC. The reference compressive strength of 56 days before burning was 63MPa. The results of specimens after burning include C0: specimens without coating, C1: cement-perlite coated specimens and C2: cement-perlite reinforced with 0.75% of glass fiber) Coated specimens are presented in **Table 6** and **Fig. 9**. All tests were conducted after removing the coatings from the specimens. The results indicate that increasing fire exposure durations leads to a reduction in compressive strength due to the decomposition of cement hydration products, the development of internal microcracks, and the increase in pore pressure within the concrete matrix. These changes weaken the internal structure of concrete and reduce its ability to resist applied compressive loads. In addition, prolonged exposure to fire allows heat to penetrate deeper into the concrete core, causing more damage and loss of structural integrity. However, the addition of different fire protective coatings highly protects the specimens of SCC and reduces the fire penetration and limits fire damage, as reported by (**Mathews et al., 2022**). The role of perlite in coatings significantly improves thermal insulation and highly increases concrete's resistance to fire, due to the ability of perlite to expand by 4–20 times its original volume when exposed to fire, which increases the fire protection of SCC as noted by (**Thanaraj et al., 2025**). While specimen C2, which is covered with fiber reinforced cement-perlite demonstrates better performance compared to the cement-perlite coated specimen C1, this presented the advantages of fibers in enhancing fire resistance. Strength maintenance is often brought by the bridging-action of fibers that minimizing the possibility of spalling and cracking after long fire exposure, as mentioned by (**Sultan et al., 2024**). Moreover, the fibers help keep the integrity of the protective coating during fire exposure by limiting crack propagation within the coating layer itself. This reduces the formation of cracks and minimizes heat transfer, and helps the coating to preserve its efficiency in fire protection for longer periods, resulting

in protecting the underneath SCC specimens. **Fig. 10** displays the specimens after conducting the compressive strength test.

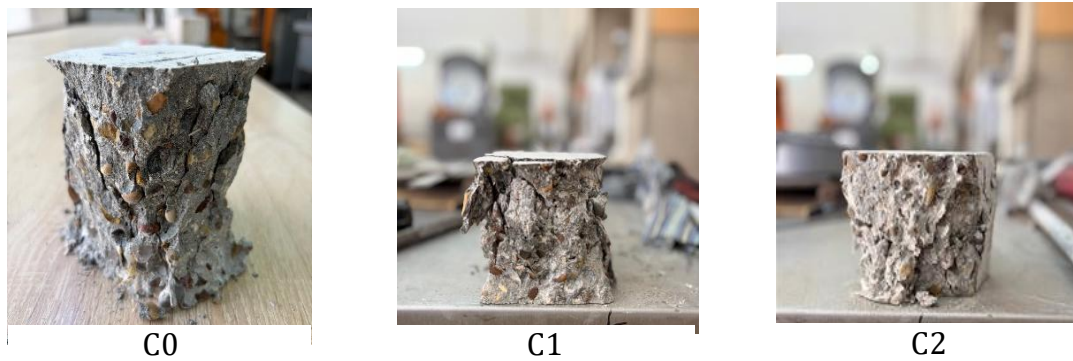
**Table 6.** Compressive strength results after fire test (MPa)

| Type of specimens | Compressive strength (MPa) |        |         |
|-------------------|----------------------------|--------|---------|
|                   | 60 min                     | 90 min | 120 min |
| C0                | 45.00                      | 32.10  | 22.90   |
| C1                | 58.20                      | 53.00  | 49.00   |
| C2                | 60.00                      | 56.00  | 51.20   |



**Figure 9.** Effect of fire exposure durations on compressive strength (MPa)

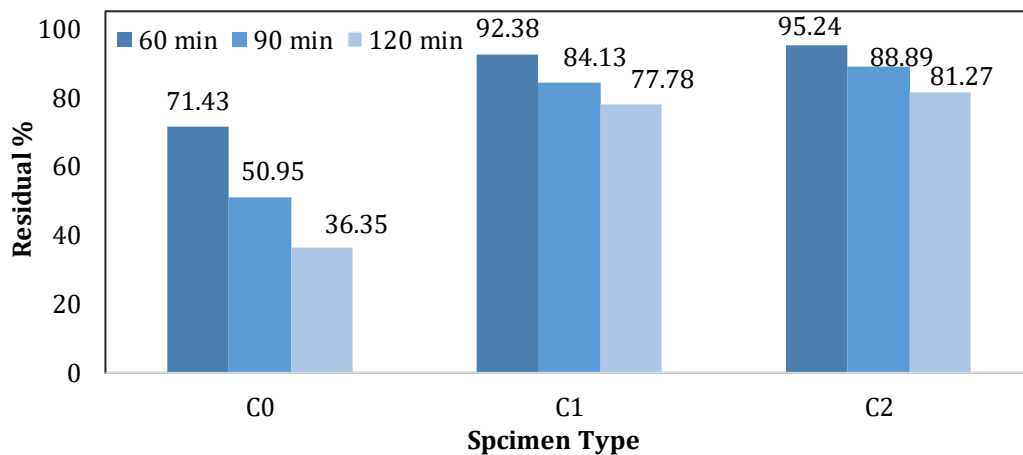
The residual compressive of each specimen is demonstrated in **Table 7** with **Fig. 11**. Findings show that longer fire exposure periods significantly lower SCC's residual compressive strength. The uncoated specimens C0 dropped extremely from 71.43% at a duration of 60 min to 50.95% and 36.35% at 90 and 120 min, respectively. This reduction indicates degradation of the SCC microstructure due to cement hydration products, development of thermal stresses inside the concrete, and formation of microcracks, all resulting in weakening of the concrete matrix and reduction of its load-carrying capacity during prolonged fire attack. In contrast, coated specimens maintained much higher values. C1 decreased from 92.38% to 84.13% and 77.78%, while C2 decreased from 95.24% to 88.89% and 81.27% within the same durations. The reduction in coated specimens is much less compared to the uncoated specimens. This shows the effectiveness of the coating layer in minimizing the damage. Furthermore, the difference between coated and uncoated specimens became more obvious with increasing fire exposure durations. This information presents the beneficial effect of the coating layers under severe fire exposure. Moreover, C2 showed higher values than C1 at all exposure durations. This demonstrates how fibers prevent cracks from expanding and help preserve strength when exposed to fire. The double effect of perlite and glass fiber bridging capability results in better preservation of compressive strength and improves the post-fire performance of SCC, especially during prolonged fire exposure.



**Figure. 10** Specimens after fire exposure and compressive strength test.

**Table 7.** Residual of compressive strength results (%)

| Type of specimens | Residual of compressive strength (%) |        |         |
|-------------------|--------------------------------------|--------|---------|
|                   | 60 min                               | 90 min | 120 min |
| C0                | 71.43%                               | 50.95% | 36.35%  |
| C1                | 92.38%                               | 84.13% | 77.78%  |
| C2                | 95.24%                               | 88.89% | 81.27%  |



**Figure. 11** Residual compressive strength after fire exposure

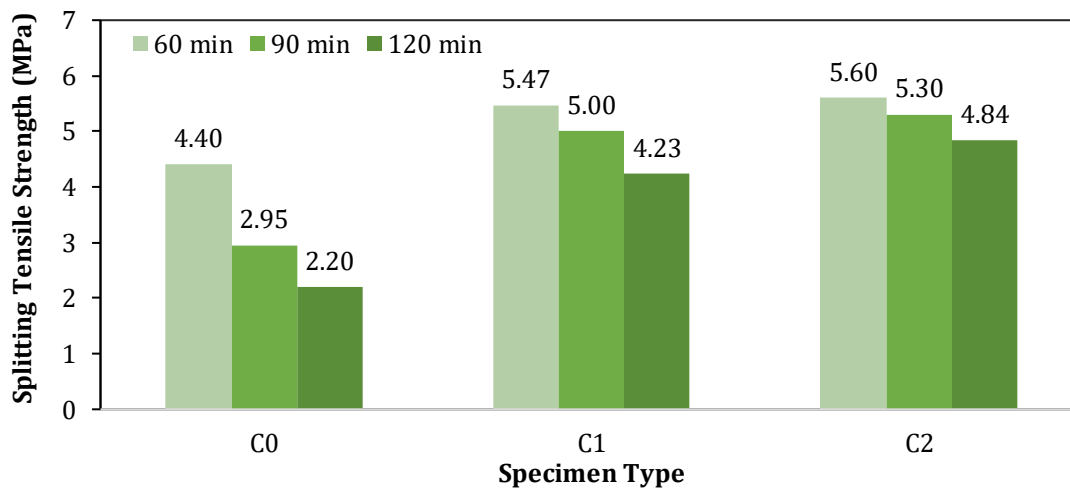
### 3.3 Splitting Tensile Strength Performance after Fire Exposure

As presented in **Table 8** and **Fig. 12**, the splitting test values after fire exposure clearly show the effectiveness of protective coatings, especially when reinforced with glass fiber. The reference splitting strength at 56 days was 6.3 MPa. After fire exposure, the uncoated specimens C0 exhibited a significant reduction to 4.4, 2.95 and 2.2 MPa at (60, 90 and 120) min, respectively, this result in significant degradation caused by high temperature and prolonged exposure, leading to the dehydration of cement hydration products and increased pore pressure, which compromises the specimens, consistent with the findings of **(Al-Radi et al., 2021)**. In contrast, coated specimens C1 and C2 maintained higher strength due to thermal insulation of cement-perlite coating, which reduces heat penetration and minimize internal damage. C2 achieved the best performance with values of 5.6, 5.3 and 4.84 MPa at (60, 90 and 120) min, this indicates that glass fiber enhances crack resistance and tensile capacity, allowing it to retain a greater portion of the original strength and providing

superior protection against thermal damage, which is consistent with the work of (Hake et al., 2020). Moreover, the fiber helps bridge the cracks and reduce their propagation and minimize the internal damage during fire exposure.

**Table 8.** Splitting tensile strength results after fire test (MPa)

| Type of specimens | Splitting tensile strength (MPa) |        |         |
|-------------------|----------------------------------|--------|---------|
|                   | 60 min                           | 90 min | 120 min |
| C0                | 4.40                             | 2.95   | 2.20    |
| C1                | 5.47                             | 5.00   | 4.23    |
| C2                | 5.60                             | 5.30   | 4.84    |



**Figure. 12** Effect of fire exposure durations on splitting tensile strength (MPa)

**Fig. 13** illustrates the specimens after the splitting test for each specimen. The residual splitting results, which are displayed in **Table 9** with **Fig. 14**, give further confirmation of the effectiveness of protective coatings. The uncoated specimens C0 dropped severely to 69.84%, 46.83% and 34.92% at (60, 90 and 120) min, while C1 decreased from 86.83% to 67.14% at 60 and 120 min and C2 showed the highest retention from 88.89% to 76.83% at same fire exposure durations, this indicating better resistance to strength loss with increasing exposure time (Mathews et al., 2023).

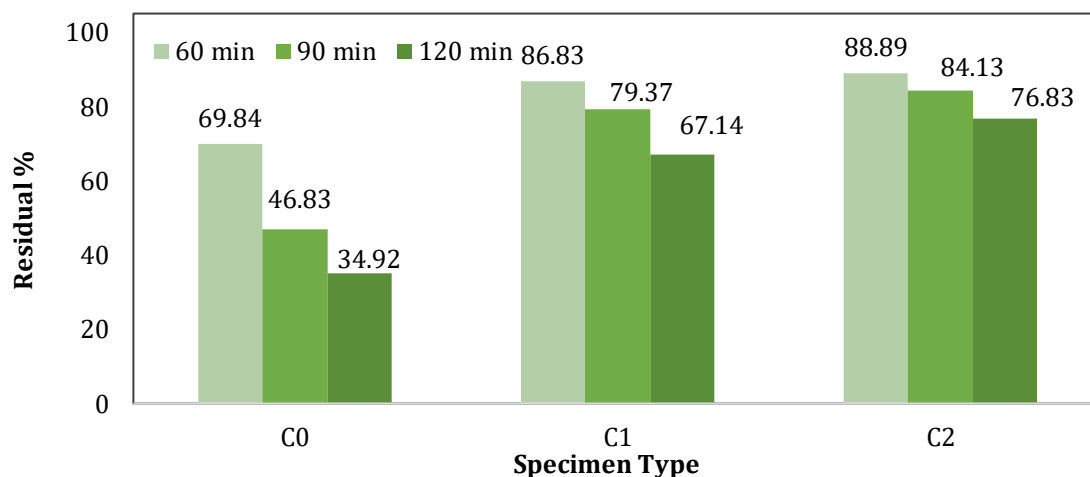


**Figure 13.** Specimens after fire exposure and splitting tensile strength test

Furthermore, the difference between coated and uncoated specimens became more showable as the exposure duration increases, presenting the ability of coating to maintain their effectiveness under prolonged exposure. The superior performance of C2 compared to C1 highlights the positive role of glass fiber in reducing damage and in enhancing post fire tensile behavior of SCC. The combined effect of perlite and glass fiber created an enhanced fire protective coating, where perlite reduced heat transfer while glass fiber controls the crack development which leads to protect SCC specimens.

**Table 9.** Residual splitting tensile strength (%).

| Type of specimens | Residual of splitting tensile strength (%) |        |         |
|-------------------|--------------------------------------------|--------|---------|
|                   | 60 min                                     | 90 min | 120 min |
| C0                | 69.84%                                     | 46.83% | 34.92%  |
| C1                | 86.83%                                     | 79.37% | 67.14%  |
| C2                | 88.89%                                     | 84.13% | 76.83%  |



**Figure 14.** Residual splitting tensile strength after fire exposure.

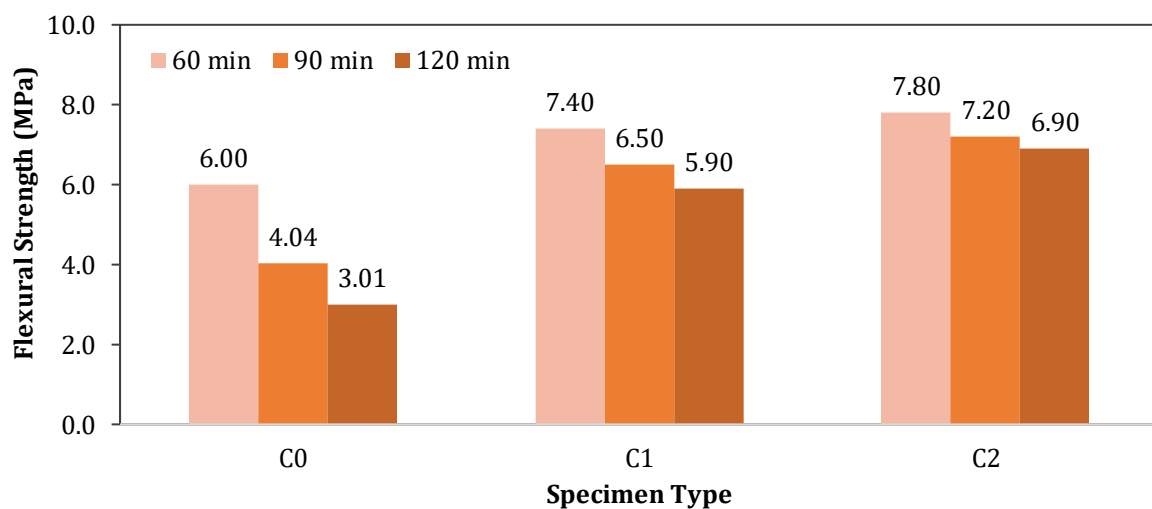
### 3.4 Flexural Strength Performance after Fire Exposure

The reference flexural strength of 56 days was 9.5 MPa. After fire test the flexural strength of uncoated specimens C0 decreased noticeably with increasing fire exposure from 6, 4.04 to 3.01 MPa at (60, 90 and 120) min. as presented in **Table 10** and **Fig. 15**. The main reasons for this reduction are the development of internal stresses, the dehydration of cement-hydration products, and the establishment of microcracks in the mix. Additionally, exposure to high temperatures weakens the mixture and reduces the SCC's flexural load-bearing ability, which conforms with the work of (Mathews et al., 2023). Since flexural strength is highly sensitive to crack initiation and propagation, the deterioration caused by high temperature and prolonged exposure durations has a greater effect on flexural strength than compressive strength, and as fire exposure increases, this leads to crack growth within the mix, resulting in a reduction in SCC strength. In contrast, the coated specimens C1 and C2 exhibited significantly better values. C1 recorded strengths ranging from 7.40 to 5.90 MPa at 60 and 120 min, while C2 achieved the highest results, from 7.80 to 6.90 MPa at the same exposure durations. This shows that coatings improve the capability of SCC to overcome the fire exposure, especially if the coating was reinforced with glass fiber due to enhanced crack

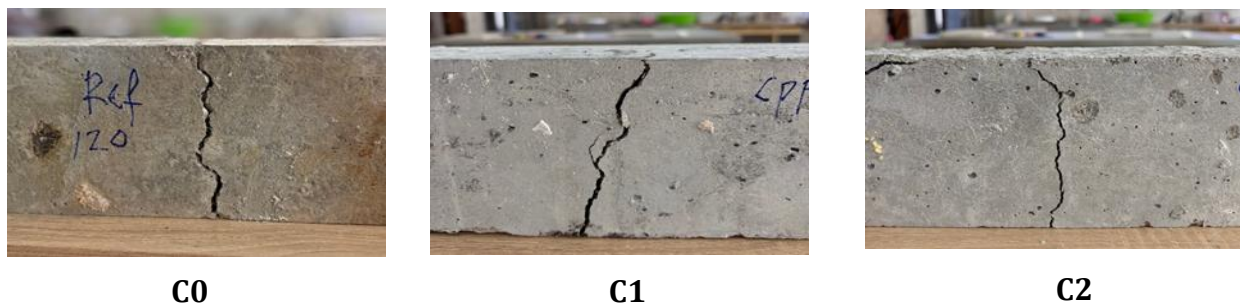
resistance through the fiber-bridging mechanism, which limited crack propagation and preserved the integrity of the coating during heating (**Sultan et al., 2024**). Furthermore, the role of both perlite and glass fiber contributed in the superior performance of C2, where perlite reduced heat transfer into concrete, while glass, on the other hand, improved the stability of the protective layer and delayed the development of cracks. **Fig. 16** illustrates specimens after the flexural test.

**Table 10.** Flexural strength results after fire test (MPa)

| Type of specimens | Flexural strength (MPa) |        |         |
|-------------------|-------------------------|--------|---------|
|                   | 60 min                  | 90 min | 120 min |
| C0                | 6.00                    | 4.04   | 3.01    |
| C1                | 7.40                    | 6.50   | 5.90    |
| C2                | 7.80                    | 7.20   | 6.90    |



**Figure 15.** Effect of fire exposure durations on flexural strength (MPa)



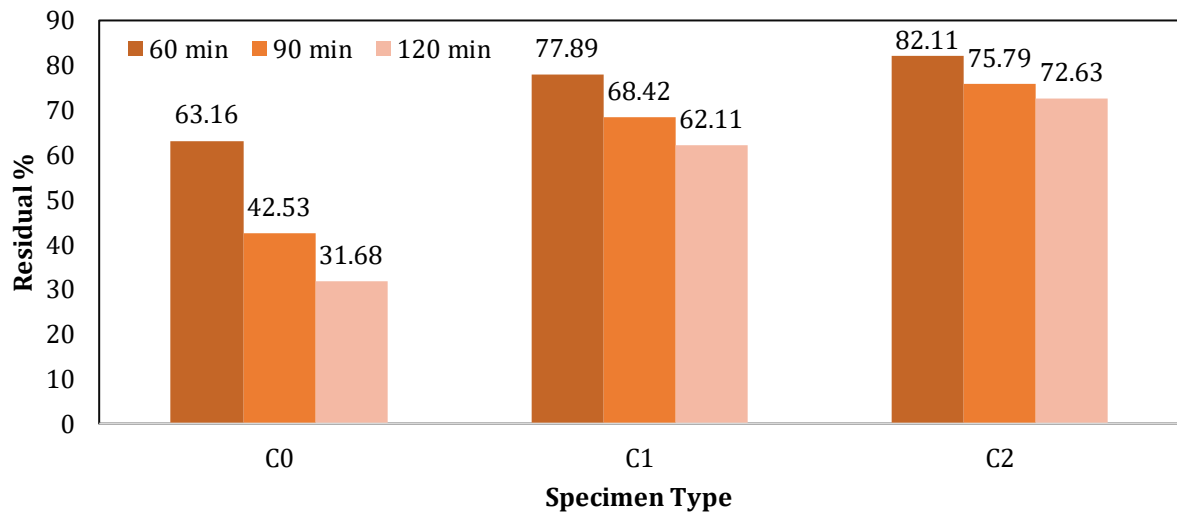
**Figure 16.** Specimens after fire exposure and flexural strength test

**Table 11** and **Fig. 17** show the percentage of residual flexural strength. The uncoated specimens kept only 63.16%, 42.53% and 31.68% after (60, 90, and 120) min, respectively, of fire exposure, reflecting significant degradation. Meanwhile, C1 maintained 77.89% to 62.11% at 60 and 120 min, and C2 showed the highest retention, ranging from 82.11% to 72.63% at the same exposure durations. These results confirm that the coating effectively limits strength loss, as noted by (**Abdelalim et al., 2009**). Overall, the incorporation of glass fibers in C2 enhances the preservation of flexural performance during prolonged fire compared to C1. Moreover, the difference between C1 and C2 became clearer at long fire

exposure, showing the important role of glass fire in fire protective coatings. This trend is in line with the findings for splitting tensile and compressive strength, where coated specimens outperformed uncoated specimens in terms of residual performance.

**Table 11.** Residual of flexural strength (%).

| Type of specimens | Residual of flexural strength (%) |        |         |
|-------------------|-----------------------------------|--------|---------|
|                   | 60 min                            | 90 min | 120 min |
| C0                | 63.16%                            | 42.53% | 31.68%  |
| C1                | 77.89%                            | 68.42% | 62.11%  |
| C2                | 82.11%                            | 75.79% | 72.63%  |



**Figure 17.** Residual flexural strength after fire exposure.

### 3.5 Visual Inspection

**Table 12** illustrates surface changes observations that occur after fire exposure during three different durations (60, 90 and 120 min), at 600 C°.

**Table 12.** Visual observations

| Specimens/<br>Durations | 60 min                                                                              | 90 min                                                                              | 120 min                                                                              | Observations                                                                                                                                                                         |
|-------------------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| C0                      |  |  |  | <b>60 min:</b> there is a slight discoloration.<br><b>90 min,</b> there are clear burn marks.<br><b>120 min,</b> the surface is severely burned.                                     |
| C1                      |  |  |  | <b>60 min:</b> minor discoloration with no visible cracks.<br><b>90 min:</b> Fine cracks become visible with increased discoloration.<br><b>120 min:</b> more wider cracks appeared. |

|    |                                                                                   |                                                                                   |                                                                                   |                                                                                                                                                                     |
|----|-----------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| C2 |  |  |  | <b>60 min:</b> No noticeable changes were visible.<br><b>90 min:</b> slight discoloration and minor cracks.<br><b>120 min:</b> formation of visible surface cracks. |
|----|-----------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------|

#### 4. CONCLUSIONS

- Self-Compacting Concrete (SCC) exhibits a clear weakness in fire resistance, and this problem becomes more serious as the exposure duration increases. However, this behavior can be enhanced by using fire-protective coatings which can preserve the strength and maintain the overall structural integrity.
- The exposure of uncoated specimens (C0) to 600 C° significantly reduces the compressive, flexural and splitting tensile strength of SCC specimens. This reduction increases and becomes severe with prolong fire exposure durations, conforming to the strong influence of exposure time on the performance of SCC.
- The use of cement–perlite coating on SCC specimens (C1) improves the fire resistance of specimens and preserve compressive, tensile and flexural strengths, demonstrating the effectiveness of the coating layer in protection of SCC specimens.
- Incorporating glass fiber with cement–perlite coating on SCC specimens (C2) shows superior performance compared to (C1), achieving higher residual strength than cement-perlite coating under different fire exposure durations, indicating improved resistance to fire.
- Coated specimens maintain substantially higher residual strength than uncoated specimens up to 95% of fire exposure under certain exposure duration. These findings demonstrate the potential of cement-perlite based coatings especially when reinforced with glass fiber, as an effective solution for improving the fire resistance and post fire structural integrity of SCC.
- From a practical perspective, coating mixture C1 can be used to improve fire resistance under moderate exposure durations. In contrast, coating mixture C2 can be applied for longer fire exposure durations.

#### NOMENCLATURE

| Symbol | Description                                                   | Symbol | Description              |
|--------|---------------------------------------------------------------|--------|--------------------------|
| C0     | Uncoated specimens                                            | SCC    | Self-compacting concrete |
| C1     | Cement – perlite coated specimens                             | SG     | Specific gravity         |
| C2     | Cement – perlite reinforced with glass fiber coated specimens | w/c    | Ratio of water/cement    |

#### Credit Authorship Contribution Statement

Umniah Ahmed: Visualization and draft writing, discussion and linguistic review. Hadeel Kh. Awad: Conducting and analyzing results and proofreading

#### Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.



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## الحماية من الحرائق للخرسانة ذاتية الرص باستخدام الطلاءات القائمة على الأسمنت والبيرلايت

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### الخلاصة

تهدف هذه الدراسة إلى تقييم فعالية الطلاءات الواقية المعتمدة على الإسمنت والبيرلايت في تحسين مقاومة الخرسانة ذاتية الرص للحريق. ولتحقيق ذلك، تم اعتماد ثلاث مجموعات من النماذج، شملت: C0 (نماذج غير مطلية)، وC1 (نماذج مطلية بطبقة إسمنت-بيرلايت)، وC2 (نماذج مطلية بطبقة إسمنت-بيرلايت مدعمة بنسبة 0.75% من الألياف الزجاجية). وقد بلغ سمك طبقة الطلاء 20 ملم لجميع الأنواع المدروسة. جرى تقييم الخواص الميكانيكية المتبقية نسبةً إلى مقاومة النماذج بعمر 56 يوماً قبل التعرض للحريق، حيث عُرضت جميع النماذج إلى درجة حرارة مقدارها 600°م ولمدد زمنية مختلفة بلغت 60 و90 و120 دقيقة. أظهرت النتائج أن زيادة مدة التعرض للحريق تؤدي إلى انخفاض ملحوظ في الخواص الميكانيكية لجميع النماذج. فقد سجلت النماذج غير المطلية انخفاضاً حاداً في المقاومة الانضغاطية المتبقية من 71.43% إلى 36.35% مع زيادة مدة التعرض من 60 إلى 120 دقيقة. في المقابل، أظهرت النماذج المطلية قدرة أعلى بكثير على الاحتفاظ بالمقاومة، إذ بلغت نسب المقاومة الانضغاطية المتبقية للنماذج C1 مقدار 92.38% و84.13% و77.78% عند مدد التعرض 60 و90 و120 دقيقة على التوالي، بينما حققت النماذج C2 قيماً أعلى بلغت 95.24% و88.89% و81.27% للفترات نفسها. كما أظهرت نتائج مقاومة الشد الانشطاري والانتشاء اتجاهات مماثلاً مع اختلاف نسب الاحتفاظ بالمقاومة. تؤكد النتائج أن الطلاءات الإسمنتية-البيرلايتية تسهم بفاعلية في تعزيز مقاومة الخرسانة ذاتية الرص للحريق والحد من التدهور في خصائصها الميكانيكية بعد التعرض الحراري. وتتمثل أصالة الدراسة في إجراء تقييم مقارنة بين الطلاء الإسمنتي-البيرلايتي التقليدي ونظيره المدعم بالألياف الزجاجية تحت مدد مختلفة من التعرض للحريق. وقد أظهر الطلاء المدعم بالألياف الزجاجية أعلى مستوى من الحماية الحرارية وأفضل قدرة على المحافظة على الخواص الميكانيكية المتبقية للخرسانة ذاتية الرص بعد التعرض للحريق مقارنةً بأنظمة الطلاء الأخرى المدروسة.

**الكلمات المفتاحية:** الخرسانة ذاتية الرص، بيرلايت المتمدد خفيف الوزن، الألياف الزجاجية، الطلاء الواقي من الحريق