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Experimental and Numerical Investigation on the Behavior and Strengthening of Fire-Damaged Reinforced Concrete Walls Using Self-Compacting Concrete Jacketing

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Fire exposure significantly compromises the load-bearing capacity of reinforced concrete (RC) structures, highlighting the critical need for effective post-fire rehabilitation strategies. There remains limited knowledge of the post-fire rehabilitation of RC walls using self-compacting concrete (SCC) jacketing to overcome the issue of enlarged sections and concreting. This study integrates experimental testing and numerical modeling to assess the effectiveness of SCC jacketing for fire-damaged walls and develop practical strengthening solutions. The objective of the first section was to determine experimentally the residual compressive strength of the normal strength concrete (NSC) exposed to temperatures ranging from 200°C to 800°C. The results obtained were then subjected to numerical analysis to evaluate the residual load-bearing capacity of the damaged walls. In the second phase, the restored load-bearing capacity was assessed using key parameters, including wall dimensions, NSC residual strength, SCC compressive strengths of 41, 51, and 58 MPa, and jacket layer thickness. The results indicate that fire intensity effects on the load-bearing capacity and stiffness of RC walls at temperatures up to 400 °C. Additionally, they demonstrate that the SCC jacketing repair method significantly enhances structural performance, with a restoration rate ranging from 71.62 % to 180.32 % of the initial wall capacity. For temperatures exceeding 800°C, it becomes more practical to use significantly greater thicknesses and higher-strength concrete. This study provides valuable insights for proposing practical and effective post-fire strengthening methods.
Keywords: RC walls, concrete jacketing, self-compacting concrete, compressive strength, load-bearing capacity.

1. INTRODUCTION

After extreme loading events, such as earthquakes and fires, reinforcing concrete (RC)structures may remain safe or experience moderate degradation. Researching effective techniques to retrofit these structures is crucial. The primary objective of repair and strengthening processes is to improve the functionality and performance of structures. This includes restoring and enhancing the strength and stiffness of structural elements and improving the overall durability of the damaged elements. Effective repair of deteriorating concrete structures requires a thorough assessment of the causes, extent, and consequences of the damage. It also involves selecting the most suitable repair techniques, procedures, and materials to address these issues. Factors like cost, ease of application, and the efficiency of the repair process are crucial when determining the best materials and methods. A damaged or deteriorated structure can often be repaired to achieve satisfactory performance levels using a range of available techniques.

1.1. Backgroundonrepairingfire-damagedreinforcedconcretestructures

Reinforced concrete (RC) members, such as columns, beams, and walls, experience a notable loss of strength and stiffness after fire exposure, highlighting the need for effective post-fire rehabilitation strategies to ensure their structural safety. Depending on the severity of the damage, several strengthening techniques may be employed. Among them, external jacketing is widely recognized as a practical and cost-effective solution. The most common jacketing techniques include concrete jacketing, steel jacketing, and composite material jacketing. These methods directly or indirectly restore the ultimate strength of the damaged members and provide confinement to the original material.

Concrete jacketing is extensively used to strengthen RC elements, enhancing the ultimate strength of fire-damaged members [1, 2]. It reduces the slenderness ratio by increasing the cross-sectional area of the RC compressive members while simultaneously increasing stiffness through additional reinforcement and an expanded cross-section. Concrete jacketing has proven highly effective in post-fire rehabilitation efforts. The type of concrete used plays a crucial role in the effectiveness of the jacketing technique.

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Its thickness is adjusted based on the desired levels of strength and stiffness. The use of normal strength concrete (NSC), however, results in an increase in the concrete section, which can be considered a drawback. This leads to changes in interior spaces and an increase in weight, negatively affecting the seismic behavior of the structure, particularly by altering the torsional center and seismic forces. To overcome these limitations, alternative materials have been introduced. Ultra-high-performance concrete (UHPC), with its superior compressive and tensile strength, enables thinner sections and greater durability [3, 4]. When reinforced with fibers, UHPC exhibits improved ductility and reduced brittleness; making it highly suitable for structural repair [5, 6].Self-compacting concrete (SCC) offers another promising solution. Capable of flowing into heavily reinforced sections without vibration, it eliminates common defects like honeycombing and segregation [7]. When combined with fibers, SCC exhibits enhanced impact resistance, fatigue strength, and ductility [8, 9], making it a viable material for jacketing with reduced section enlargement. Steel jacketing, originally developed for seismic retrofitting, provides passive confinement and shear enhancement in RC columns [10, 11]. It may, however, be susceptible to buckling in plastic hinge zones, particularly in rectangular sections, a limitation that can be mitigated with stiffeners [12]. In practice, stirrups and steel angles are often used in retrofitting strategies [13, 14].

Composite jacketing, which combines concrete and steel, has also shown promising results in restoring load-bearing capacity [15, 16]. In parallel, fiber-reinforced polymer (FRP)jacketing has gained traction due to its high strength-to-weight and stiffness-to-weight ratios, along with excellent corrosion resistance [17 – 19]. FRP systems using CFRP, AFRP, or GFRP fibers embedded in a matrix enhance confinement, stiffness, and ductility in damaged RC members [20 – 22].

1.2. Research motivation and objectives

Concrete jacketing is a well-established strengthening method, but its effectiveness in the post-fire rehabilitation of RC walls remains insufficiently explored. Moreover, conventional jacketing using NSC increases a wall's cross-sectional area, which can conflict with architectural and functional design constraints. This limitation highlights the need for alternative materials that can restore structural performance without compromising space or increasing weight. SCC offers a promising solution due to its flowability and reduced vibration, making it ideal for confined or complex geometries. In this context, the objective of this research is to investigate the use of reinforced concrete jacketing (RCJ) with SCC to restore and enhance the strength of fire-damaged RC walls while minimizing increases in thickness.

In the first phase, the residual load-bearing capacity of RC walls was assessed by considering key parameters, such as fire-exposure scenarios, peak temperatures, wall height and thickness, and NSC residual strength obtained experimentally. Secondly, the post-strengthening performance of the retrofitted walls was evaluated using SCC with different compressive strengths (41.8 MPa, 51 MPa, and 58 MPa); the wall specimens considered have a height of 3.00 meters and thicknesses of 15 cm and 20 cm.

2. BEHAVIOR OF REINFORCED CONCRETE WALLS AFTER FIRE EXPOSURE

Reinforced concrete walls (RCWs) are currently used in precast structures as separation facings and load-bearing walls, in high-rise buildings as a bracing system, and in various types of structures. All seismic regulations recommend the use of shear walls in earthquake-prone regions [23 – 25]. In a structural system, walls support both vertical and horizontal loads and provide temperature insulation between different compartments within a building because of concrete's low thermal conductivity and non-combustibility, effectively suppressing the spread of fire in buildings. It can be used as a fire wall and remain structurally stable even after prolonged exposure to fire [26].

Fire exposure can lead to substantial damage in concrete components. Therefore, RCWs should be designed to withstand fire loads and eventual loads, such as seismic actions [27]. It is crucial to evaluate the performance and residual fire resistance of RCWs to allow for a well-informed decision on whether to retrofit or demolish the fire-damaged sections, since buildings are subjected to numerous fires each year [28]. Unfortunately, the thermo-mechanical behavior of RCWs subjected to fire has not been extensively studied [29], especially their residual mechanical proprieties. Research on post-fire-damaged concrete structures and materials is crucial for effectively overcoming these challenges.

Previous studies have primarily focused on the fire behavior of RCWs during the heating phase [30], with limited attention paid to their performance during and after the cooling phase, despite evidence of significant damage occurring in this period [31 – 36]. Xu and Xiao [37, 38] developed simplified approaches to evaluate the post-fire mechanical performance of RC shear walls, providing valuable insight into their residual strength. Ngo et al. [39] investigated the response of RC walls to hydrocarbon fires, while Deshpande et al. [40, 41] analyzed the combined effect of fire and seismic loading on squat shear walls. Mueller and Kurama [42, 43] conducted full-scale tests and identified a strong correlation between fire-resistance indices and the degradation of mechanical properties. Baghdadi et al. [44] performed comprehensive experimental and numerical analyses to assess the residual vertical and lateral load-bearing capacities of fire-damaged RC walls, emphasizing key parameters, such as wall thickness, slenderness ratio, and boundary conditions. Similarly, Kang et al. [45] and Chun et al. [46] highlighted the influence of geometric characteristics and fire-induced damage on the axial strength of RC walls.

More recent studies by Afaghi and Abdollahzadeh [47], as well as Guergah et al. [48], explored the role of cooling rates and extinguishing methods in the risk of delayed collapse, underscoring the need for post-fire assessments under realistic conditions.

3. EXPERIMENTAL STUDY

3.1. Raw material and mixture proportions

This section offers a comprehensive overview of the fire test specimens, experimental apparatus, and methodologies employed in the studies and tests. It is important to note that all these investigations were conducted in university laboratories.

3.1.1. Normal-strength concrete

The cement used was ordinary Portland (CEM I 42.5 R), characterized by a specific gravity of 3.22 and a Blaine fineness measurement of 3783 g/cm² according to Algerian standards (NA 2595/2006 and NA 231/2006).

Aggregate materials:

1. Quarry sand (0/3): The fineness modulus and sand equivalent were determined to be 2.71 and 71 %, respectively, in accordance with French specifications (NF P 18-554, NF P 18-555, NF P 18-560, NF P 18-598, NF P 18-544, and NF P 18-561).
2. Gravel: The crushed limestone aggregate was used in three specific size ranges: 15/25, 8/15, and 3/8. The quality and compliance of these aggregates met the relevant standards.

Tap water was used for the mixing and curing processes (XP-P 18-303).

Mix proportions: the hardened concrete achieved a density of 2354 kg/m³. Cylindrical specimens 160 mm in diameter and 320 mm in height were manufactured, emblematic of normal-strength concrete(NSC). The details of the mix proportions are systematically detailed in Table 1. The characteristic compressive strength was found to be 34 MPa at 28 days.

3.1.2.Self-compacting concrete

Self-compacting concrete (SCC) was specifically designed for the repair of shear wall concrete damaged by fire. It can be used in damaged zones without the need for vibration; it will easily flow into cracks and voids, even in the presence of dense reinforcement, providing an effective repair method [49, 50].

The SCC formulation was designed to achieve an optimal higher strength, which is particularly advantageous in restoring fire-damaged structures in narrow areas. The experiments conducted on the fresh concrete mix to determine the ideal quantity of superplasticizer (Sp) included the V-funnel test. The Abrams cone slump test was identified as 2.1 % relative to the weight of the cement, a proportion found to bestow the desired characteristics on the self-compacting concrete. The study involves three distinct SCC formulations, labeled SSC1, SSC2, and SCC3, with water-to-cement ratios of 0.5, 0.45, and 0.42, respectively. The hardened concrete results of all SCC variants are provided in Table 2, while the detailed mix compositions of the corresponding mixtures are presented in Table 3.

Table 2. Values of compressive strength of all SCC

Mixture	SCC1	SCC2	SCC3
f_{c28} ,MPa	41	51	58

3.2. Program of heating processes

Concrete cylinders were heated in a uniform environment for different heating durations. A controlled temperature evolution was applied, ranging from 3 to 8 °C/min, to reach target temperatures of 200, 400, 600, and 800 °C. A stabilization phase was considered following the heating phase, depending on the peak temperature; the furnace was then turned off and the cylinders were allowed to cool naturally until the specimens cooled to room temperature. Fig. 1 depicts the time–temperature profile in the furnace.

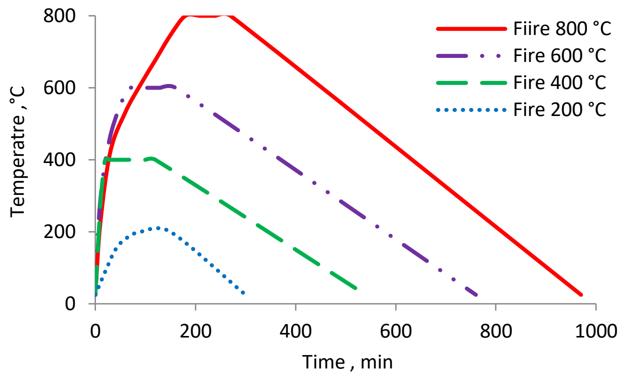


Fig. 1. Time-temperature curves recorded in an electric heating furnace

4. EXPERIMENTAL RESULTS AND ANALYSIS

4.1. Compressive residual strength of NSC

Table 4 presents the test results, showing the ratio of the residual compressive strength after heating to 200, 400, 600, and 800 °C compared to the initial compressive strength measured at room temperature. Consistent decreases in compressive strength of 20 %, 28 %, 64 %, and 86 %, respectively, were found.

Table 1. Normal strength concrete designs in kg/m^3

Concrete ingredients	Cement	Gravel 15/25	Gravel8/15	Gravel 3/8	Sand 0/3	Water	G/S ratio	Water-cement ratio
Mix proportions	350	728	298	149	710	193	1.65	0.55

Table 3. Proportions of the mixture components of the self-compacting concrete used, in kg/m^3

Mixture abbreviation	Cement	Water	Sand	Gravel		S_P, %	W/C Ratio	G/S Ratio
			0/5	3/8	8/16			
SCC1	400	200	855.77	295.25	590.45	2.1	0.50	SCC1
SCC2	420	188.5	863.80	281.40	569.50	2.1	0.45	SCC2
SCC3	450	188.5	865.85	271.31	549.62	2.1	0.42	SCC3

Table 4. Residual compressive strength (*fc,r*) for the NSC

Characteristic value offc, 20°, MPa	Temperature, °C	Characteristic value of *fc,r*, MPa	Ratio *fc,r* / *fc*,20°	*fc,r* loss, %
34.00	200	27.30	0.80	20.00
	400	24.43	0.72	28.00
	600	12.30	0.36	64.00
	800	4.99	0.14	86.00

The obtained results were juxtaposed with the proposed models in Eurocode (2005) [51] by Chang et al. [52] and those proposed by Li and Franssen [53]. Up to 400 °C, the results closely align with the Eurocode model. Beyond this temperature, however, they deviate and show agreement with the Li and Chang models, thereby supporting the findings of several previous studies.

As indicated by [53], there is an additional strength loss during the cooling phase and after cooling, depending on the cooling regime. We observed that the strength loss that occurred after cooling was significantly higher than the total loss proposed in Eurocode (2005) [51], as presented in Fig. 2.

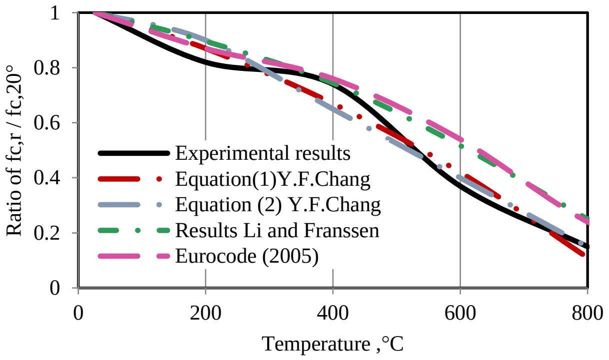


Fig. 2. Reduction of residual compressive strength for NSC compared to other results

5. NUMERICAL ASSESSMENT OF CONCRETE WALLS UNDER FIRE CONDITIONS

The first objective of this phase was to perform numerical analyses using the SAFIR non-linear finite element program [54] to evaluate the residual strength of the walls exposed to fire. The walls' behavior during fire was controlled by a combination of concrete and reinforced bar response [55]. This analysis comprises two uncoupled parts: thermal analysis, which allows the evaluation of the history of fire temperature distribution, and the structural analysis, which gives the structure's response. See Fig. 3.

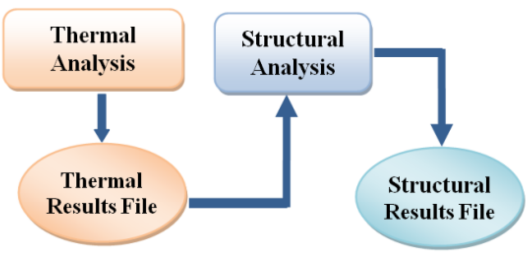


Fig. 3. Analysis methodology

5.1. High-temperature material models

The thermal properties used in this study were selected based on Eurocode (2005) [51]. According to Eurocode 2005, as the temperature of concrete increases, its thermal conductivity decreases. This reduction in thermal conductivity is a crucial factor in heat-transfer analysis. It was assumed that this reduction in thermal conductivity was irreversible, meaning that, during the cooling phase, the thermal conductivity of the concrete remained at the level corresponding to the highest temperature it experienced. The concrete model presented in Table 5 requires two parameters to describe the behavior of concrete at high temperatures: the strain associated with the peak stress ($\varepsilon_{c1,\theta}$) and the compressive strength ($f_{c,\theta}$) at a given temperature.

Table 5. Relationships between stress and strain [56]

Strain-range	Stress σ (θ)
$\varepsilon_{c,\theta} \leq \varepsilon_{c1,\theta}$	$\sigma_{c,\theta} = \dfrac{3.\varepsilon_{c,\theta}\cdot f_{c,\theta}}{\varepsilon_{c1,\theta}\left[2+\left(\frac{\varepsilon_{c,\theta}}{\varepsilon_{c1,\theta}}\right)^3\right]}$
$\varepsilon_{c1,\theta} \leq \varepsilon_{c,\theta} \leq \varepsilon_{cu1,\theta}$	When dealing with numbers, descending branch is used. Both linear and non-linear models can be applied.

The mechanical properties of the reinforcing bars are supposed to be reversible. This indicates that the strength returns to their initial values upon cooling.

5.2. Results and discussion

5.2.1. Thermal analysis

The same time–temperature curves used in the experimental study were applied as thermal loads in the thermal analysis of the walls. Fig. 4 illustrates the predicted temperature distribution across a 25 cm wall section when exposed to a 600 °C fire during both the heating and cooling phases.

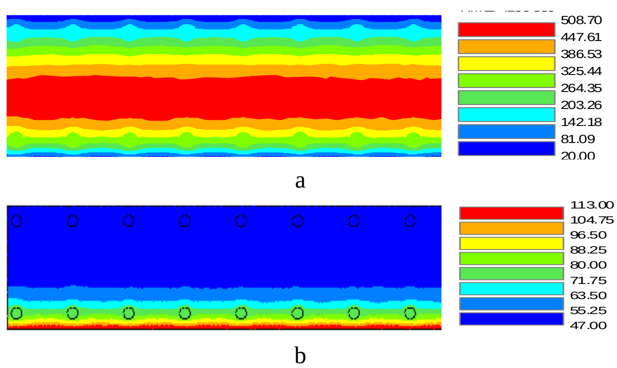


Fig. 4. Illustration of e predicted temperatures within the thickness wall of 25cm: a – heating phase; b – cooling phase

Understanding temperature variations within the wall thickness during a fire is crucial for accurate structural analysis.

5.2.2.Parametric structural analysis

In this analysis, it is assumed that the compressive strength of concrete does not recover during cold. This assumption is a fundamental aspect of the predictions made in this paper and is the basis for the validity of the conclusions. The residual strengths obtained in experimental part were implemented in the numerical model (Spalling was not considered in this study). The parameters considered in this section are the following:
1. Peak temperature impact;
2. Influence of the effective height of the wall;
3. Impact of wall thickness;
4. Influence of various support conditions.

5.2.2.1. Influence of wall height

Table 6 provides detailed results on how the wall height influences its residual load-carrying capacity after being subjected to natural fire of 600 °Cand 800 °C, as well as under normal conditions ($N_{20°C}$).The wall thickness considered was fixed at 15 cm. The data clearly demonstrate that taller walls experience a more significant reduction in residual capacity.

Table 6. Influence of height on load-carrying capacity

Height, m	Load-carrying capacity, kN		
	$N_{20°C}$	After fire	
		600°C	800°C
3	2622	680	280
4	1686	270	120
5	1020	160	60

5.2.2.2. Influence of wall thickness

Table 7 illustrates the influence of wall thickness on the load-carrying capacity of a 3 m high wall. The analysis considers three thicknesses: 15 cm, 20 cm, and 25 cm, with the wall exposed to fire intensities of 600 °C and 800 °C.

The results were compared to the load-bearing capacity under normal conditions ($N_{20°C}$). The findings indicate that thicker walls exhibit greater resilience when subjected to high-temperature exposure, maintaining a higher load-carrying capacity compared to thinner walls.

Table 7. Influence of wall thickness on load-carrying capacity

Thickness of the wall, cm	Load-carrying capacity, kN			
	$N_{20°C}$	$N_{r,400°C}$	$N_{r,600°C}$	$N_{r,800°C}$
15	2622	1206	680	280
20	4152	2491	2000	1300
25	7524	6019	5000	4000

5.2.2.3. Effects of various support conditions

Two different wall support configurations were considered in this study:
1. Pinned at both ends (simply supported condition);
2. Fixed at the bottom and pinned at the top (semi-rigid condition).

Table 8 presents the results illustrating the evolution of load capacity for a wall with a thickness of 15 cm and a height of 3.00 m after exposure to various fire intensities.

The findings indicate that support conditions significantly influence the wall's structural performance. In all fire scenarios, the fixed-base wall demonstrated greater load-carrying capacity and resilience compared to the pinned wall, highlighting the importance of boundary conditions in post-fire structural behavior.

Table 8. Influence of various support conditions on load-bearing capacity

Support conditions	Pinned–pinned wall		Fixed–pinned wall	
$N_{20°C}$,kN	2622	$N_r/N_{20°C}$	3405	$N_r/N_{20°C}$
$N_{r,400°C}$,kN	1208	0.46	2350	0.69
$N_{r,600°C}$,kN	680	0.26	1650	0.48
$N_{r,800°C}$,kN	280	0.10	800	0.23

6. SELF-COMPACTING CONCRETE JACKETING STRENGTHENING METHOD

Strengthening and repairing RCWs with SCC after fire exposure is a crucial process in structural rehabilitation in civil engineering. It is essential to consider both the structural integrity and fire resistance of walls when fire-induced damage has compromised their performance. SCC, with its enhanced flowability and superior strength properties, provides an effective solution for oversizing reinforced elements using a NSC liner while also addressing the challenge of placing concrete in heavily reinforced areas and preventing segregation.

6.1. SCC compressive strength

When repairing RCWs using an SCC jacket, the choice of compressive strength is critical to ensure compatibility with the existing structure, structural adequacy, and long-term durability. The compressive strengths of SCC were obtained by testing 8 standard test cylinders (32 cm high and 16 cm in diameter) at 28 days. The test results are presented in Table 2.

6.2. Strengthening and rehabilitation procedure

The thickness to be removed from a degraded wall before applying self-compacting concrete depends on several factors, including the extent of degradation, the depth of the damaged areas, and structural requirements. Typically, the total thickness removed varies from 3cm to 10 cm, depending on the severity of fire-induced deterioration of the wall.

For the retrofitted walls, the geometrical dimensions considered include thicknesses of 15 cm and 20 cm and a height of 300 cm. The reinforcement area consists of 10 bars (Ø12 mm) arranged symmetrically to avoid SCC cracking, with a concrete cover of 2.5 cm. The NSC strength used in the analysis corresponds to the residual strength calculated in the first phase, which varies depending on the fire intensity. The strengthening process varies based on wall thickness:
1. for the 15 cm thick wall, two 5 cm layers of SCC were applied on either side.

2. for the 20 cm thick wall, two 3 cm layers of SCC were used.

The compressive strengths of the self-compacting concrete (SCC) layers considered were 41 MPa, 51 MPa, and 58 MPa. Each SCC layer was lightly reinforced with 10 bars of 6 mm diameter to enhance structural integrity and performance. Prior to this, a 2 cm layer of fire-damaged concrete was removed from both sides to ensure proper adhesion and structural integrity (see Fig. 5).

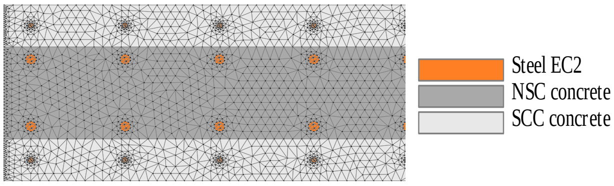


Fig. 5. RC wall Repaired using SCC jacketing technique

6.3. Findings and discussion

6.3.1. Numerical analysis

The finite element software SAFIR was used to perform 2D nonlinear analysis. The reinforced concrete (RC) walls were modeled using the fiber element approach, which allows for the integration of different materials with distinct properties, ensuring a more accurate representation of their behavior.

6.3.2. Load-carrying capacity (N_{CC})

The load-carrying capacity of the repaired wall depends on several factors, including the thickness of the strengthened layers, the compressive strength of the, and the bond between the original and new concrete layers. The contact between the original concrete and the jacketing layer is assumed to be perfect, an assumption justified by the surface treatment applied to the damaged concrete. According to Eurocode 2 (EN 1992-1-1) [62], the load-carrying capacity of the repaired wall under concentric compression is calculated by combining the contributions of concrete and reinforcement following the principles of composite or homogeneous section analysis, using the following equation:

$$N_{CC} = f_{cr}.A_{NSC} + f_{c28}.A_{SCC} + f_y.A_S \quad (1)$$

where N_{CC} is the load-carrying capacity of repaired walls, kN; f_{cr} is the residual compressive strength of NSC, MPa; f_{c28} is the compressive strength of SCC at 28 days, MPa; $A_{,NSC}$ is the cross-sectional area of NSC, cm²,subtracting 2 cm from each layer (A_{NSC} = (thickness-4 cm) × 100 cm); A_{SCC} is the cross-sectional area of SCC concrete, cm²;f_y is the yield strength of reinforcement steel, MPa; A_s is the total area of reinforcement steel, cm².

This equation incorporates the mechanical properties of the materials and the interface bond strength, which are critical for determining the structural integrity and performance of the repaired wall under loading conditions.

In general, higher compressive strengths in SCC jackets result in higher effectiveness ratios, demonstrating that stronger jackets are more efficient in restoring load-carrying capacity.

The strengthening efficiency (SE%) was evaluated using Eq. 2, which is commonly employed to express the strength-recovery ratio of a structural element relative to its original capacity prior to fire exposure:

$$SE(\%) = \frac{N_{CC} - N_{20°C}}{N_{20°C}} \times 100, \quad (2)$$

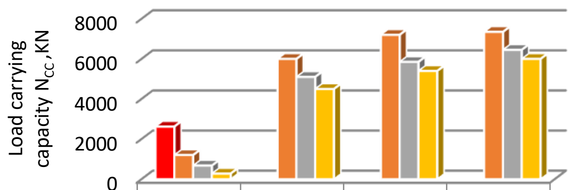
where $SE(\%)$ is the strengthening efficiency ratio, N_{CC} is the load capacity of strengthened wall, kN ; $N_{20°C}$ is the load capacity of original wall at 20°C, kN.

This formula quantifies the effectiveness of SCC jacketing by evaluating the relative increase in load-bearing capacity after strengthening compared to the original capacity of the wall.

6.3.2.1. 15 cm RC wall strengthened with a 5 cm thick SCC jacket

The load-carrying capacity for the original wall of 15 cm under normal conditions is $N_{20°C}$ = 2622 kN (before fire exposure).As fire intensity increases, the load-carrying capacity decreases, which is expected due to the thermal degradation of concrete and reinforcement steel, resulting in the following percentage reductions: at 400°C, the capacity drops by 54 % (1206 kN); at 600°C, the loss reaches 74.06 % (680 kN); at 800°C, the reduction is 89.32 % (280 kN).

Fig. 6 presents the N_{CC} of a strengthened wall of 15 cm with an SCC jacket of different compressive strengths.



	Before Repair	SCC 41 MPa	SCC 51 Mpa	SCC 58 MPa
At 20°C	2622			
After 400°C	1206	6000	7200	7350
After 600°C	680	5100	5850	6450
After 800°C	280	4500	5400	6000

Fig. 6. Load-carrying capacity of wall of 15 cm using an SCC jacket with different compressive strengths

Fig. 7 provides insights into the effectiveness ratio of wall-repair measures, highlighting the ability of SCC jackets to restore load-carrying capacity. The key interpretations are as follows:

— At the same SCC strength of 41 MPa, the efficiency ratio ranges from 71.62 % to 128.83 %, indicating that SCC jackets significantly improve the structural performance of fire-damaged walls. The higher the fire temperature, the lower the effectiveness of strengthening, but it remains significant. Lower-strength SCC jackets (41 MPa) show lower effectiveness ratios**,** meaning they provide less reinforcement to the fire-damaged walls.

— At the same temperature, the variation in effectiveness is directly linked to the compressive strength of the SCC jacket. Higher compressive strengths result in better recovery of load-carrying capacity.

— SCC jackets with higher compressive strength (58 MPa) demonstrate greater efficiency in restoring wall strength, as they enhance load redistribution and structural integrity.

— At 800 °C, even with SCC (58 MPa), the effectiveness is reduced to 128.83 %, indicating that extreme temperatures compromise reinforcement performance.

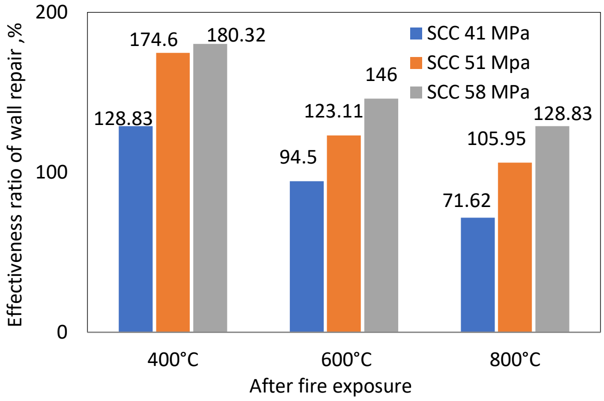
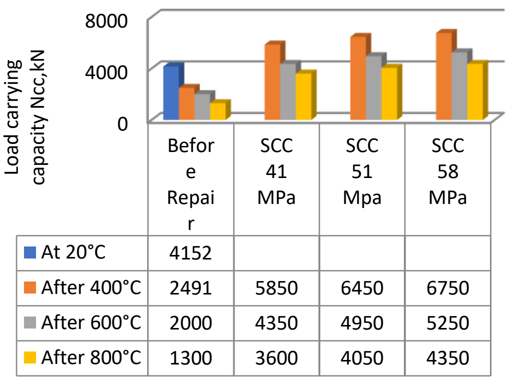


Fig. 7. Effectiveness of post-fire wall strength techniques after fire exposure

6.3.2.2. 20cm RC wall strengthened with a 3cm thick SCC jacket

Fig. 8presents the evolution of load-carrying capacity of a fire-damaged wall after strengthening using an SCC jacket. The original wall (unexposed to fire) has a load-carrying capacity of $N_{20°C} = 4152$ kN. The following remarks can be drawn: at 400 °C, N_{CC} is reduced to 2491 kN (40 % reduction); at 600 °C, N_{CC} further decreases to 2000 kN (51.83 % reduction); at 800 °C, N_{CC} drops significantly to 1300 kN (68.68 % reduction).



	Before Repair	SCC 41 MPa	SCC 51 Mpa	SCC 58 MPa
At 20°C	4152			
After 400°C	2491	5850	6450	6750
After 600°C	2000	4350	4950	5250
After 800°C	1300	3600	4050	4350

Fig. 8. Load-carrying capacity of the wall of 20 cm of thickness using an SCC jacket after fire exposure

Fig. 9shows the effectiveness ratio of SCC jacketing (RW SC-J) at restoring the wall strength of a 20 cm thick wall after different levels of fire exposure and assessing how the proposed repair technique enhances structural wall performance. The results indicate that:

— At moderate fire exposure (400 °C), all SCC jackets contribute significantly to restoring load capacity, with higher compressive strength leading to better performance.

— At higher fire exposure (600 °C), the effectiveness ratio decreases significantly, suggesting that moderate-strength SCC jackets struggle to fully restore capacity**.** Higher compressive strengths (58 MPa) remain more effective at preserving structural integrity.

— At extreme fire exposure (800 °C), SCC jackets with compressive strengths of 41 MPa and 51 MPa failed to restore the wall's original capacity, resulting in negative effectiveness values. This indicates that, in such cases, the strength of the strengthened element remains lower than its initial value before fire damage due to the significant strength degradation experienced at 800 °C.

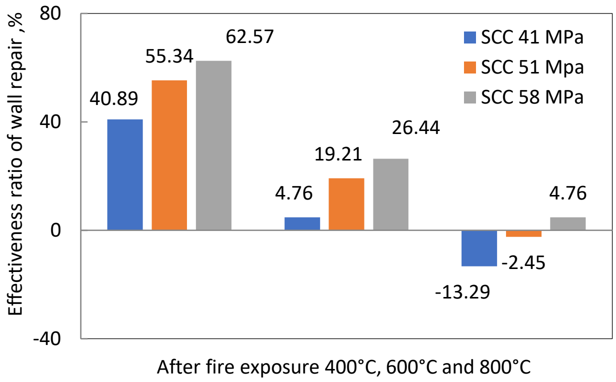


Fig. 9. Effectiveness ratio of 20 cm RCWs with an SCC jacket

— Only the58 MPa SCC jacket provides minimal recovery (4.76 %);in cases of severe fire damage, the repair capability of SCC jackets is limited when the layer thickness is too low or when the SCC compressive strength is insufficient. These factors are determinant for the structural integrity recovery of the repaired wall in terms of load-bearing capacity, stiffness, and overall performance, highlighting the importance of adequate layer thickness and high-strength SCC for optimal post-fire rehabilitation. For extreme temperatures exceeding 800°C, it becomes more practical to use significantly greater thicknesses and higher-strength concrete.

7. CONCLUSIONS

Based on the analysis of experimental and numerical results, the following conclusions can be drawn:

1. The application of self-compacting concrete (SCC) jackets is an effective rehabilitation method for fire-damaged reinforced concrete (RC) walls**.**
2. The thickness and compressive strength of the SCC jacket are critical factors in restoring the load-bearing capacity of fire-exposed structures.
3. In cases of severe fire damage, the repair capability of SCC jackets is limited when the layer thickness is too low. Therefore, a minimum thickness of 5 cm is recommended**.**
4. Higher-strength SCC provides better recovery of load-bearing capacity of RC walls (SCC 58 MPa consistently outperforms SCC51 MPa and 41 MPa).
5. SCC jacketing is highly effective for temperatures below 600 °C, where it significantly restores the structural integrity of walls. SCC of compressive strengths 41 MPa, 51 MPa, and 58 MPa considerably improves the wall’s post-fire strengthening.

6. Beyond 600 °C, concrete and reinforcing steel experience severe thermal damage. The effectiveness of SCC repair depends on both its strength and the applied thickness.
7. The selection of SCC strength should be optimized based on fire severity and the required level of structural rehabilitation.
8. These findings provide critical insights for engineers working on fire-resistant design and post-fire rehabilitation**.** Usinghigher-strengthSCC jackets is an effective strategy, particularly forcritical structural elements exposed to high fire intensities, helping to partially or fully restore lost structuralcapacity.
9. This research reinforces the importance of optimizing SCC strength and thickness to enhance post-fire rehabilitation strategies in structural engineering. It provides valuable knowledge for fire-resistant structural design and offers practical recommendations to improve the durability and safety of fire-exposed RC walls.

Although this study offers valuable insights, it is limited to specific wall geometries, fire scenarios, and SCC strength classes. The adopted approach combining experimental data on residual NSC strength with validated numerical modeling remains practical and relevant. Future research should explore other structural configurations and assess long-term durability, particularly with fiber-reinforced SCC. Large-scale experimental validation would further support the practical implementation of SCC jacketing techniques.

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