Experimental Investigation on the Flexural Response of RC Beams Strengthened with NSM Steel Bars at Elevated Temperatures

Lyn Dee Goh
Faculty of Civil Engineering, Universiti Teknologi MARA

Muhammad Adam Syahmi Dazulhisham
Faculty of Civil Engineering, Universiti Teknologi MARA

Muhammad Arif Ikmal Abdul Halim
Faculty of Civil Engineering, Universiti Teknologi MARA

N.H Abd Ghafar
Faculty of Civil Engineering and Built Environment, Universiti Tun Hussein Onn Malaysia

https://doi.org/10.5109/7395518

出版情報：Proceedings of International Exchange and Innovation Conference on Engineering & Sciences (IEICES). 11, pp.198-203, 2025-10-30. International Exchange and Innovation Conference on Engineering & Sciences
バージョン：

Experimental Investigation on the Flexural Response of RC Beams Strengthened with NSM Steel Bars at Elevated Temperatures

Lyn Dee Goh[1], Muhammad Adam Syahmi Dazulhisham[1], Muhammad Arif Ikmal Abdul Halim[1], N.H Abd Ghafar[2]
[1]Faculty of Civil Engineering, Universiti Teknologi MARA, Cawangan Pulau Pinang, Penang, Malaysia, [2]Faculty of Civil Engineering and Built Environment, Universiti Tun Hussein Onn Malaysia, Batu Pahat, Johor, Malaysia.
gohlyndee147@uitm.edu.my

Abstract: *With increasing concern over the fire performance of existing structures, effective retrofitting methods for reinforced concrete (RC) elements under elevated temperatures are gaining critical attention. This study investigates the flexural behavior of RC beams strengthened with near-surface mounted (NSM) steel bars when subjected to elevated temperatures. A total of six beams were tested under three temperature regimes: ambient (25°C), moderate (200°C), and elevated (600°C). For each condition, one unstrengthen control beam and one NSM-strengthened beam were evaluated under four-point bending. Results indicate that NSM strengthening with steel bars effectively enhanced load-carrying capacity and stiffness across all thermal exposures. At room temperature, the strengthened beam achieved a 31.6% increase in ultimate load compared to its control counterpart. At 600°C, the NSM-strengthened beam exhibited a 26.7% higher load capacity than the unstrengthen beam, demonstrating the thermal resilience of the embedded steel bars and anchorage system. These findings highlight the potential of NSM with steel bars as a viable strengthening strategy for RC structures exposed to fire or high-temperature environments.*

Keywords: steel bar; elevated temperature; RC beam; flexural performance; strengthening

1. INTRODUCTION

Reinforced Concrete (RC) structures have long been integral to modern infrastructure due to their robustness, economic viability, and durability under typical environmental conditions. Nevertheless, RC structures are susceptible to performance deterioration under prolonged loading and environmental influences such as corrosion, fatigue, and particularly elevated temperatures resulting from fire incidents or similar thermal events [1-3].

Thermal exposure can severely compromise the structural integrity of RC, leading to microstructural degradation, moisture loss, and reduced mechanical performance. Ghazy et al. [4] demonstrated that RC slabs exposed to 600°C experienced a significant reduction in flexural strength. However, slabs strengthened with high-performance concrete, especially those incorporating hybrid fibers, showed enhanced post-fire performance, including improvements in ultimate load capacity, stiffness, and ductility.

In response to the structural challenges posed by thermal events, various strengthening methods have been explored to maintain or enhance the performance of existing RC elements. Among these, the Near Surface Mounted (NSM) reinforcement method has emerged as a highly effective and practical approach. The NSM method involves embedding reinforcement materials into grooves near the concrete surface, which improves bond characteristics, mitigates corrosion risks, and reduces surface exposure compared to externally bonded systems. However, the deterioration of bond strength at elevated temperatures remains a critical concern for structural integrity. Aslani [5] demonstrated that elevated thermal exposure alters bond behaviour in both normal and high-strength concrete, affecting the post-fire flexural capacity of RC structures. Similarly, Ghajari et al. [6] reported that residual bond strength may decrease by up to 65% after exposure to 700°C, with significant dependency on residual compressive strength and confinement levels. These findings underscore the importance of strengthening strategies like NSM that offer enhanced bond performance and can potentially mitigate the adverse effects of fire on RC structures.

A wide range of materials has been investigated for NSM strengthening, predominantly Fiber Reinforced Polymers (FRP), due to their lightweight and high strength-to-weight ratio. FRP-based systems have been widely applied to enhance the shear resistance of RC members, offering notable improvements in load-bearing behaviour under structural stress conditions [7]. However, despite these advantages, FRP materials suffer from significant strength degradation and bond deterioration at elevated temperatures due to the thermally sensitive nature of their polymer matrices and epoxy adhesives [8]. Studies have shown that the tensile strength and bond strength of FRP composites decrease with increasing temperature [9] and the bond between NSM FRP strips and concrete is greatly affected by high temperatures, which can lead to premature debonding [10].

Steel reinforcement employed in the NSM method offers a promising alternative owing to its high thermal stability, ductility, and proven compatibility with concrete. Previous studies have demonstrated that NSM steel strengthening can significantly enhance the flexural performance of RC elements under ambient conditions, leading to increased load-carrying capacity, improved energy absorption, and superior crack control [11]. This is consistent with broader developments in concrete technology, including the integration of fiber reinforcement to enhance tensile behaviour and crack resistance, as reviewed by Chakraborty et al. [12]. However, detailed experimental data on the performance of NSM steel-reinforced beams exposed to elevated temperatures such as those encountered during structural fires remain limited.

Despite the increasing adoption of NSM strengthening methods, most existing research has focused on FRP reinforcements, which are known to experience significant performance degradation when exposed to elevated temperatures. In contrast, conventional steel bars, although widely available and cost-effective, have received comparatively limited attention as NSM reinforcements, particularly under thermal loading conditions. This study addresses this gap by experimentally investigating the flexural performance of RC beams strengthened with NSM-installed steel bars and subjected to elevated temperatures of up to 600°C. By comparing the mechanical behaviour of strengthened and unstrengthen specimens across a range of temperatures, this research provides novel insights into the viability and thermal resilience of steel-based NSM systems, highlighting their potential as a robust solution for post-fire structural rehabilitation.

2. METHODOLOGY

2.1 Test Specimens and Materials

This investigation aimed to assess the flexural performance of RC beams strengthened using NSM steel bars, particularly under elevated temperatures. A total of six beam specimens were fabricated and tested under three thermal regimes: ambient (25°C), moderate (200°C), and elevated (600°C). For each thermal condition, one control (unstrengthen) beam and one NSM-strengthened beam were tested. The designation and characteristics of each specimen are summarized in Table 1.

Table 1: Specimen Designation and Description

Specimen ID	Strengthening Type	Exposure Temperature
CB	Control	Room (25°C)
CB200	Control	200°C
CB600	Control	600°C
ST	NSM with Steel Bar	Room (25°C)
ST200	NSM with Steel Bar	200°C
ST600	NSM with Steel Bar	600°C

Each beam measured 750 mm in length, 200 mm in depth, and 150 mm in width. The longitudinal reinforcement consisted of two 12 mm diameter high-yield steel bars at the bottom (tension zone) and two 10 mm diameter bars at the top (compression zone). Shear reinforcement was provided by 6 mm diameter stirrups spaced at 100 mm intervals along the beam length.

The concrete used throughout the study had a target 28-day compressive strength of approximately 30 MPa. The steel reinforcement was characterized through tensile tests conducted as part of this study. The results indicated a yield strength of approximately 620 MPa for the tension reinforcement and 600 MPa for the compression reinforcement. Both types of reinforcement exhibited an elastic modulus of 200 GA. These values were obtained from direct experimental testing carried out in the preliminary phase of this study, rather than assumed from standard specifications.

2.2 NSM Strengthening Procedure

To implement the NSM method, a central longitudinal groove was cut along the soffit of each beam. The groove measured 20 mm in width and 20 mm in depth. For enhanced anchorage, a vertical slot of approximately 125 mm height was added at both beam ends, forming an L-shaped cavity. Steel rebars with 10 mm diameter were embedded into the groove and bonded using a proprietary high-performance grout (Sika grout 215), which achieved a compressive strength exceeding 60 MPa after 28 days of curing. Fig. 1 presents the RC beam specimen strengthened with conventional steel bar using NSM method adopted in this study.

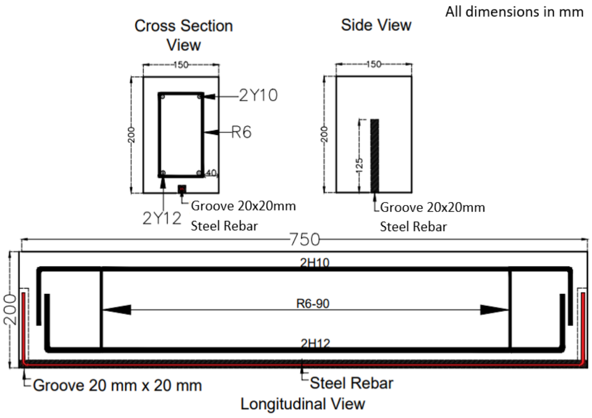

Fig. 1. NSM RC Beam Configuration and Detailing

2.3 Thermal Conditioning

Beams designated for thermal exposure were placed inside an electric furnace and subjected to a gradual temperature increase at a rate of about 5°C/min until the target temperature (either 200°C or 600°C) was reached. The temperature was held constant for one hour to ensure uniform heat distribution. Following exposure, specimens were allowed to cool naturally to room temperature before mechanical testing.

2.4 Flexural Testing Setup

All beams were tested under four-point bending with a clear span of 700 mm between supports. The loading was applied incrementally via a displacement-controlled hydraulic actuator until failure occurred. Displacement transducers were positioned at midspan to capture vertical deflection, while applied loads were recorded using calibrated load cells. The testing procedure complied with relevant provisions in the Eurocode for structural concrete testing. The test setup adopted in the laboratory is as illustrated in Fig. 2 [13].

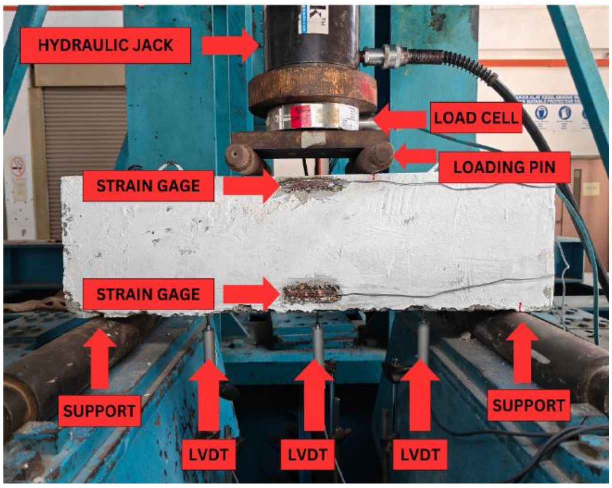

Fig. 2. Test setup.

3. RESULTS AND DISCUSSION

3.1 Load–Deflection Behaviour of Control Beams (CB Series)

Fig. 3 presents the experimental load–deflection responses of the control beams (CB series), tested at varying thermal exposures (room temperature, 200°C, and 600°C), serving as a baseline reference for evaluating the strengthened beams (ST series).

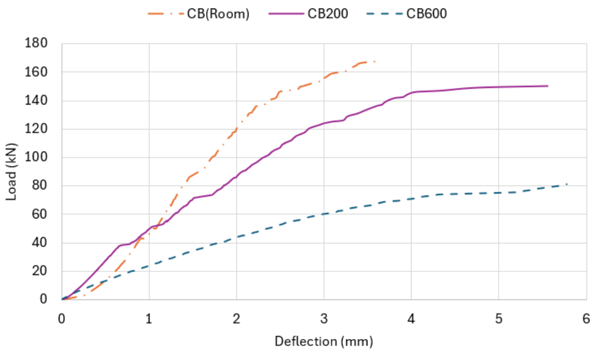

Fig. 3. Load-deflection curves for CB series.

The control beam tested at room temperature (CB) exhibited typical load–deflection behaviour characteristic of RC beams subjected to flexural loading. Initial cracking occurred at approximately 45 kN, corresponding to a midspan deflection of about 1.35 mm. Following initial cracking, the beam displayed a gradual reduction in stiffness, indicating progressive cracking and internal stress redistribution. The ultimate load reached approximately 167.6 ken with a corresponding deflection of about 3.64 mm. The load–deflection curve indicated a relatively sharp decline post-peak, signifying a clear flexural failure mode with limited post-peak deformation capacity. The failure manifested as significant flexural cracking at midspan without shear distress or anchorage failure.

When exposed to a moderate temperature of 200°C, the control beam (CB200) demonstrated noticeable degradation in stiffness and ultimate strength. The initial cracking load was observed lower at approximately 40 ken, occurring at a deflection of 0.82 mm, reflecting early onset cracking due to thermal-induced microstructural weakening of concrete. The ultimate load recorded was around 150.32 ken, representing roughly a 10% reduction compared to the ambient temperature CB specimen. However, the maximum deflection at failure notably increased to approximately 5.56 mm, suggesting increased deformation capacity possibly due to thermal softening effects. The failure remained predominantly flexural with pronounced crack propagation at midspan.

The beam exposed to an elevated temperature of 600°C (CB600) exhibited severe performance deterioration. First cracking was observed at a significantly reduced load of approximately 18 ken, with a deflection of about 0.60 mm. The ultimate load decreased markedly to approximately 81.4 ken, representing about a 51% reduction compared to CB200 and a substantial 51.4% reduction relative to the room temperature beam (CB). Although CB600 attained a relatively high maximum deflection of around 5.78 mm, its load–deflection curve was distinctly flatter post-cracking, indicating significantly reduced stress redistribution and limited ductility. Severe surface damage and concrete spalling observed after testing further underscored the vulnerability of strengthened RC beams to high thermal exposure.

The data from these control specimens establish a fundamental baseline against which the performance of NSM-strengthened beams (ST series) under similar thermal conditions can be comparatively evaluated.

3.2 Load–Deflection Behavior of NSM Steel-Strengthened Beams (ST Series)

This section presents the flexural response of NSM steel-strengthened RC beams under three thermal conditions: room temperature (25°C), 200°C, and 600°C. The load–deflection relationships derived from experimental testing are illustrated in Fig. 4, providing insights into the structural behaviour and performance stability of the NSM system across thermal exposures.

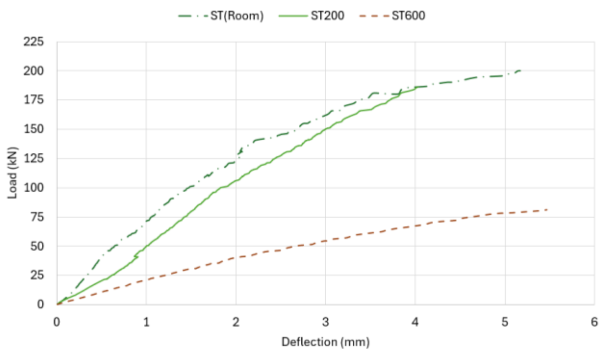

Fig. 4. Load-deflection curves for ST series.

The NSM-strengthened beam tested at room temperature (ST) demonstrated significant improvement in both strength and deformation capacity. The first visible flexural crack was observed at a load of approximately 52 ken with a corresponding midspan deflection of 0.85 mm. The beam exhibited good stiffness and sustained load incrementally until failure, achieving an ultimate load of 200.10 ken at a deflection of 5.17 mm. Failure occurred within the flexural zone, with multiple wide cracks were observed forming near midspan. The embedded steel bars effectively delayed crack propagation and enhanced energy absorption. The load–deflection curve showed a gradual reduction in slope beyond cracking, indicating increased toughness and an efficient load redistribution mechanism.

At 200°C, the ST200 beam retained its high-performance profile, albeit with a slight reduction in capacity. The first crack occurred at 45 ken and 0.93 mm deflection, indicating only a modest change from room temperature behaviour. The beam reached an ultimate load of 190.45 ken at a deflection of 5.06 mm, equivalent to approximately 95% of the ST beam's peak capacity. The crack pattern was observed to remain flexural in nature, with wider spacing and increased spread near midspan. The steel bars maintained reliable bond characteristics, and no anchorage distress was observed.

For the beam exposed to 600°C (ST600), more evident degradation was recorded. The first crack appeared at a load of 45 ken, but at a significantly larger deflection of 2.20 mm, suggesting stiffness deterioration due to thermal softening of the surrounding concrete. The beam attained a maximum load of 81.55 ken at 5.56 mm deflection. Although the curve flattened earlier compared to ST and ST200, the beam maintained considerable deformation capacity, with a less abrupt post-peak decline, indicating some residual toughness despite thermal exposure.

3.3 Comparative Summary of Mechanical Performance

A comparative evaluation of all six specimens, comprising unstrengthen control beams (CB series) and NSM-strengthened beams (ST series), was conducted to assess the influence of thermal exposure and NSM reinforcement on flexural performance. Table 2 presents the summary of the first crack load, corresponding deflection, ultimate load, and peak deflection.

Table 2: Load–deflection summary

Specimen	Temperature (°C)	First Crack Load (kN)	Deflection at Crack (mm)	Ultimate Load (kN)	Peak Deflection (mm)
CB	25	45	1.35	167.6	3.64
CB200	200	40	0.82	150.72	5.56
CB600	600	18	0.60	84.48	5.78
ST	25	52	0.85	200.10	5.17
ST200	200	45	0.93	190.45	5.06
ST600	600	45	2.20	81.55	5.56

From the results, all NSM-strengthened beams exhibited higher flexural capacity than their strengthened counterparts at the same thermal exposure level. At ambient temperature, the ST specimen reached an ultimate load of 200.10 ken, which is approximately 19 percent higher than the 167.60 ken recorded for CB. Even at 600°C, ST600 still recorded a slightly higher ultimate load (81.55 ken) than CB600 (81.40 ken), indicating that the NSM system retained functional integrity despite high thermal degradation.

The ST series also showed improved early-stage stiffness retention. While the CB specimens exhibited a decreasing trend in first crack load with rising temperature, from 45 ken down to 18 KN, the ST series consistently initiated flexural cracking at around 45 KN across all temperatures. This suggests that the embedded steel bars provided effective early resistance against crack propagation, even when the surrounding concrete had thermally softened. The presence of embedded steel bars can provide early resistance against crack propagation [13]. The steel bars bridge cracks, preventing them from widening and propagating further into the concrete [14]. This is especially significant in the context of thermal softening, where the concrete matrix loses strength and stiffness due to elevated temperatures. The ST600 beam also exhibited a significantly higher deflection at crack initiation (2.20 mm) compared to CB600 (0.60 mm), indicating reduced initial stiffness but enhanced deformation capacity. This increased flexibility likely results from the thermally softened concrete, which was still effectively confined by the embedded steel reinforcement. While CB600 showed signs of brittle failure, the ST600 beam was able to sustain greater displacement before failure, implying improved toughness despite the thermal exposure.

From a structural engineering perspective, the use of conventional steel bars in NSM configurations demonstrates strong potential as a fire-resilient retrofitting strategy. Unlike FRP systems, which tend to suffer severe thermal degradation, steel-based NSM strengthening retains mechanical properties up to critical temperatures with proper detailing and protective cover. Moreover, conventional steel allows for ease of sourcing, design familiarity, and cost-effectiveness in practical applications.

Therefore, these results support the inclusion of NSM steel bars in both fire-resistant design and post-fire repair scenarios for RC members. However, designers must give careful attention to factors such as bar anchorage, adhesive type, cover thickness, and insulation strategies to fully harness the advantages of this strengthening method in high-temperature applications.

3.4 Load–Deflection Curve Analysis and Comparative Discussion

The consolidated load–deflection curves for all six specimens are presented in Fig. 5. These curves illustrate the flexural response of both unstrengthen (CB series) and NSM-strengthened (ST series) beams subjected to ambient and elevated temperatures. The plotted data reveals trends in stiffness, ultimate capacity, and post-cracking ductility that distinguish the performance of each group.

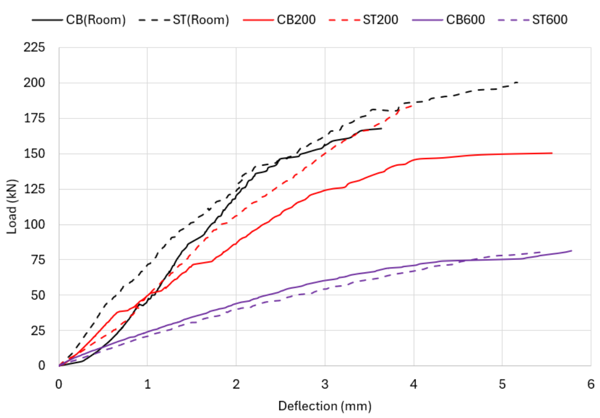

Fig. 5. Consolidated load–deflection curves

At 25°C, the CB beam exhibited a relatively steep initial slope, indicating moderate stiffness, followed by a sudden drop in curvature post-peak. In contrast, the ST beam demonstrated enhanced ductility and a more gradual post-peak descent, reaching a higher ultimate load of 200.10 kN with improved deflection performance of 5.17 mm. The strengthening provided by NSM steel bars effectively enhanced energy absorption and delayed structural failure.

At 200°C, both CB200 and ST200 beams showed changes in stiffness, yet the extent of degradation differed significantly. The CB200 beam's capacity dropped to 150.32 kN, while ST200 beam retained 190.45 kN, or approximately 95 percent of its original strength. The curve for ST200 beam remained similar in shape to that of ST beam, indicating that the NSM system retained bond integrity and flexural efficiency under moderate thermal exposure. Notably, deflection at peak load was relatively stable for both CB200 and ST200 beams, showing limited compromise in ductility.

At 600°C, thermal effects became more apparent. CB600 beam experienced substantial stiffness reduction and an abrupt failure mode, with an ultimate load of 81.40 kN. ST600 beam, though affected by thermal softening, still carried a comparable peak load of 81.55 kN. However, its deflection profile showed a longer sustained deformation phase and higher deflection at crack onset (2.20 mm), demonstrating the steel bar's continued role in load redistribution and crack bridging even under severe heating.

Across all cases, the initial stiffness, represented by the slope of the linear portion of each curve, declined with increasing temperature. This trend was more pronounced in the CB series. The ST specimens, despite exposure to thermal stress, showed retained or moderated stiffness losses and a delay in failure onset. The use of embedded steel bars enhanced continuity and crack control, which became increasingly critical under high thermal degradation.

In summary, the load–deflection analysis verifies that the NSM-strengthened beams not only improved structural behaviour under ambient conditions but also maintained substantial performance under fire-like exposures. The strengthening system contributed to higher strength retention, prolonged deflection capacity, and enhanced toughness, suggesting its relevance for structural elements expected to withstand thermal impact. These behavioural trends provide valuable insights for fire-resilient design or retrofitting of RC components in critical structures.

4. CONCLUSION

This study experimentally assessed the flexural performance of RC beams strengthened with NSM conventional steel bars when exposed to elevated temperatures. A total of six beam specimens, including control (CB) and NSM-strengthened (ST) beams, were tested under ambient, 200°C, and 600°C conditions.

The results demonstrated that NSM strengthening with conventional steel bars significantly enhanced both load-carrying capacity and deformation performance, even after thermal exposure. At room temperature, the ST beam achieved an ultimate load of 200.10 kN, representing a 31.6 percent increase compared to the CB beam which recorded 152.00 kN. At 200°C, the ST200 specimen reached 190.45 KN, which is 26.3 percent higher than the CB200 value of 150.72 kN. At 600°C, despite the severe thermal exposure, ST600 maintained an ultimate load of 81.55 kN, while CB600 dropped to 60.00 kN, resulting in a 35.9 percent improvement.

The NSM system delayed initial cracking, enhanced post-cracking ductility, and provided considerable residual strength under elevated temperature conditions. These observations indicate that NSM using steel bars is an effective and thermally stable retrofitting method for RC beams.

From a structural design perspective, the findings support the integration of NSM steel bars into fire-resilient retrofitting strategies. The use of conventional steel not only simplifies material procurement and compatibility with construction practices but also offers a cost-efficient alternative to fire-sensitive systems such as fibre-reinforced polymers. To ensure reliable performance, engineers should account for anchorage details, cover thickness, and adhesive thermal resistance when applying NSM methods in elevated temperature scenarios.

5. ACKNOWLEDGEMENT

The authors would like to express their sincere gratitude to University Technology MARA, Cadangan Pulau Pinang, for the continuous support, facilities, and resources provided throughout the course of this study.

6. REFERENCES

[1] L. Mishra, U.K. Sharma, Behaviour of deteriorated reinforced concrete columns under elevated temperatures, Fire Technology. 60 (2024) 1569–1607.

[2] M. Yağan, F.M. Özkal, M.O. Öztürk, M. Polat, Investigation of the structural behavior of reinforced concrete beams at elevated temperatures, ACS Omega. 9 (2024) 9593–9602.

[3] Y. Hui-qun, Behavior of reinforced concrete structure under and after high temperature: A review, J. Chongqing Archit. Univ. (2003).

[4] M.F. Ghazy, M.A. Abd Elaty, N.M. Zalhaf, Performance of normal strength concrete slab strengthened with high-performance concrete after exposure to elevated temperature, Fire Technology. 59 (2023) 2415–2453.

[5] F. Aslani, B. Samali, Predicting the bond between concrete and reinforcing steel at elevated temperatures, Structural Engineering and Mechanics. 48 (2013) 643–660.

[6] F.A. Ghajari, H. Yousefpour, Residual bond-slip behavior in reinforced concrete members exposed to elevated temperatures, Struct. Concr. 24 (2022) 3281–3298.

[7] J.T. Heia, M.M. Islam, A. Islam, An investigation towards the effects of using fiber reinforced polymers in the enhancement of shear strength of reinforced concrete beams, Proceedings of the International Exchange and Innovation Conference on Engineering & Sciences (IEICES) 7 (2021) 103–108.

[8] V.J. Kalyani, D.D. Joshi, P.V. Patel, Study of the behaviour of FRP materials and epoxy adhesives under elevated temperature, Materials Today: Proceedings (2023).

[9] Y. Li, X. Liu, M. Wu, Mechanical properties of FRP-strengthened concrete at elevated temperature, Construction and Building Materials 134 (2017) 424–432.
[10] A. Mohammed, N.T.K. Al-Saadi, R. Al-Mahaidi, Bond behaviour between NSM CFRP strips and concrete at high temperature using innovative high-strength self-compacting cementitious adhesive (IHSSC-CA) made with graphene oxide, Construction and Building Materials 127 (2016) 872–883.
[11] L. Mishra, U.K. Sharma, Behaviour of deteriorated reinforced concrete columns under elevated temperatures, Fire Technology 60 (2024) 1569–1607.
[12] R. Chakraborty, T. Paul, A.B.S. Ornob, A review on tensile behavior of different kinds of fiber reinforced concrete, Proceedings of the International Exchange and Innovation Conference on Engineering & Sciences (IEICES) 6 (2020) 231–237.
[13] M.A.S. Dazulhisham, M.A.I.A. Halim, L.D. Goh, Near-surface mounted technology in strengthening reinforced concrete beam, International Journal of Sustainable Construction Engineering and Technology 15 (1) (2024) 211–225.
[13] L. Van Hong Bui, B. Stitmannaithum, T. Ueda, Experimental investigation of concrete beams strengthened with embedded through-section steel and FRP bars, Journal of Composites for Construction 24(5) (2020).
[14] L. Qin, Z. Xu, Q. Liu, Z. Bai, C. Wang, Q. Luo, Y. Yuan, Experimental study on mechanical properties of coal gangue base geopolymer recycled aggregate concrete reinforced by steel fiber and nano-Al_2O_3, Reviews on Advanced Materials Science 62(1) (2023).