

High-Temperature Behaviour of Frp Composite Slabs-A Review

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Abstract—Fiber-reinforced polymer (FRP) composites are increasingly used as internal reinforcement and external strengthening systems in concrete slabs because they offer high tensile strength, corrosion resistance, low self-weight and electromagnetic neutrality. Their main limitation in building and bridge-deck applications is sensitivity to elevated temperature. The polymer matrix softens near the glass transition temperature, decomposes at higher temperatures, and progressively loses its ability to transfer stress among fibres and across the FRP-concrete interface. This review paper synthesizes reputed Scopus-indexed journal studies on the high-temperature behaviour of FRP composite slabs and related reinforced concrete members. The review covers GFRP, CFRP and natural/bio-based FRP systems; temperature-dependent mechanical degradation; bond deterioration; concrete cover effects; fire endurance of slabs; impact response after fire; thermal protection systems; and finite element modelling approaches. The study also integrates current dissertation-level ANSYS modelling outputs for FRP-strengthened RCC slab elements to demonstrate the relevance of stress, deformation, support and load-

transfer visualisation in fire-oriented numerical research. The review confirms that concrete cover thickness, cool anchorage length, insulation strategy, FRP type, reinforcement ratio, slab boundary restraint and coupled heat-transfer/structural modelling assumptions govern the predicted fire response. Although recent 3D sequentially coupled thermal-stress models have improved prediction of fire-exposed GFRP slabs, research gaps remain in validated bond-slip modelling, spalling treatment, realistic fire exposure, post-fire residual capacity and comparison between steel-RC, FRP-RC and hybrid reinforced slabs. A research framework is therefore proposed for future high-fidelity numerical modelling and experimental validation of FRP composite slabs under standard and realistic fire scenarios.

Index Terms—FRP composite slabs; GFRP reinforcement; CFRP strengthening; elevated temperature; fire resistance; ISO 834; concrete cover; bond degradation; finite element analysis; ANSYS; thermo-mechanical coupling.

Nomenclature

Symbol/Abbreviation	Meaning	Design relevance
FRP	Fiber reinforced polymer	Non-corrosive reinforcement/strengthening material
GFRP	Glass fiber reinforced polymer	Most common FRP bar used in slab fire studies
CFRP	Carbon fiber reinforced polymer	Higher stiffness and strength; externally bonded or NSM systems
T _g	Glass transition temperature	Temperature range where polymer matrix softens
T _d	Decomposition temperature	Temperature range where polymer matrix decomposes

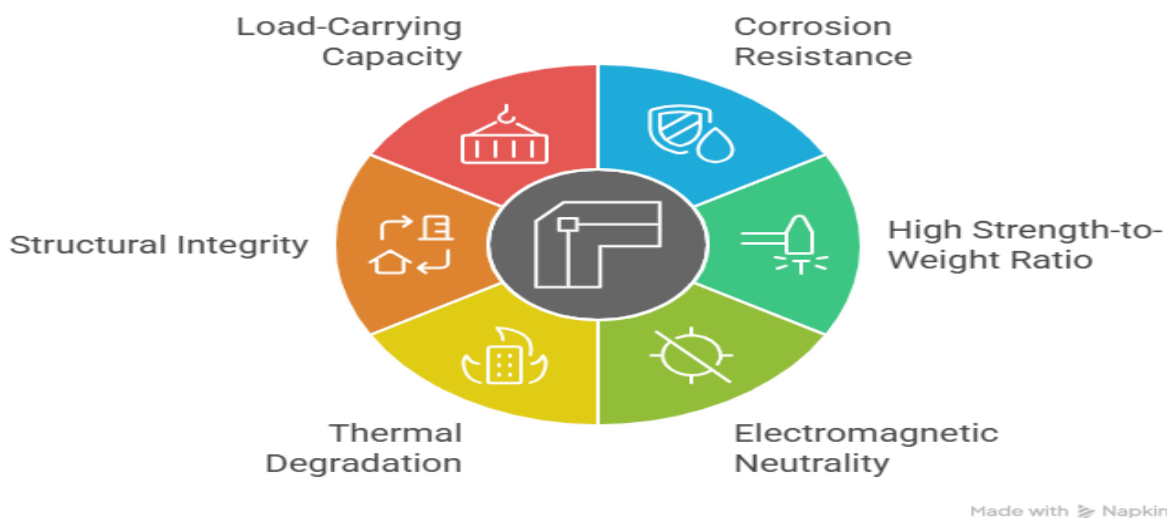
ISO 834	Standard fire curve	Common benchmark for fire exposure modelling
FEA/FEM	Finite element analysis/method	Thermal-stress simulation and parametric design
CDP	Concrete damage plasticity	Common concrete cracking/crushing constitutive model

1. Introduction

FRP reinforcement has become an important alternative to steel reinforcement in reinforced concrete members exposed to corrosion-prone and electrically sensitive environments. The core appeal of FRP in slabs is its high strength-to-weight ratio, non-corrosive behaviour, ease of installation in strengthening applications and reduced maintenance requirement. In the uploaded dissertation synopsis, the proposed study is specifically focused on the high-temperature behaviour of FRP composite slabs and adopts ANSYS-based thermo-mechanical modelling of FRP-reinforced concrete slab elements. The synopsis highlights FRP is sensitive to fire, loss of stiffness and strength, bond degradation and need for validation of numerical modelling as key research problems. The fire resistance of FRP-reinforced concrete is significantly different from that of steel-RC. When temperature is high, steel gradually loses strength and stiffness, but maintains ductility; FRP

bars are severely affected by softening of polymer matrix, decomposition of resin, and deterioration of bond. Although the glass fibres are relatively thermally stable, during the resin degradation temperature, the composite action cannot be guaranteed when the matrix and FRP-concrete bond fails to transfer shear well. This may cause higher deflection, loss of residual capacity, and changes in cracking patterns and early failure of FRP reinforcement for slab systems. It is an appropriate topic for a review paper as individual studies have addressed different aspects, including degradation of properties of materials, fire endurance tests, and protection of the concrete cover. What is meant by the term bond capacity, impact after fire and numerical thermal-structural modelling? A common interpretation is necessary for future dissertation-level modelling and to establish publishable research gaps for manuscripts in Scopus.

FRP-Reinforced Concrete Under Heat



Graphical overview of critical performance issues in FRP-reinforced concrete under high temperature, adapted from the dissertation synopsis

II. REVIEW METHODOLOGY AND SCOPE

The review was organized as journal papers published by publishers with good reputation and index that include Elsevier, ASCE, Springer, SAGE and MDPI/Polymers. Conference-only papers, non-indexed sources and general websites were excluded unless they were used only to gain background (standards) information. Only publications that had DOI and direct relevance to FRP-reinforced and/or FRP-strengthened concrete structural members subjected to elevated temperatures were considered.

The selected studies have been categorized as follows:

(i) material degradation at high temperature of FRP bars and laminates; (ii) bond and anchorage behaviour of FRP to concrete at elevated temperature; (iii) fire endurance of slabs and fire endurance of floors; (iv) numerical modelling and sequential thermal-stress analysis; and (v) fire protection, insulation and post/fire performance. The present dissertation research gives modelling context by providing images of the geometry, boundary conditions, stress contours and deformation plots created in ANSYS.

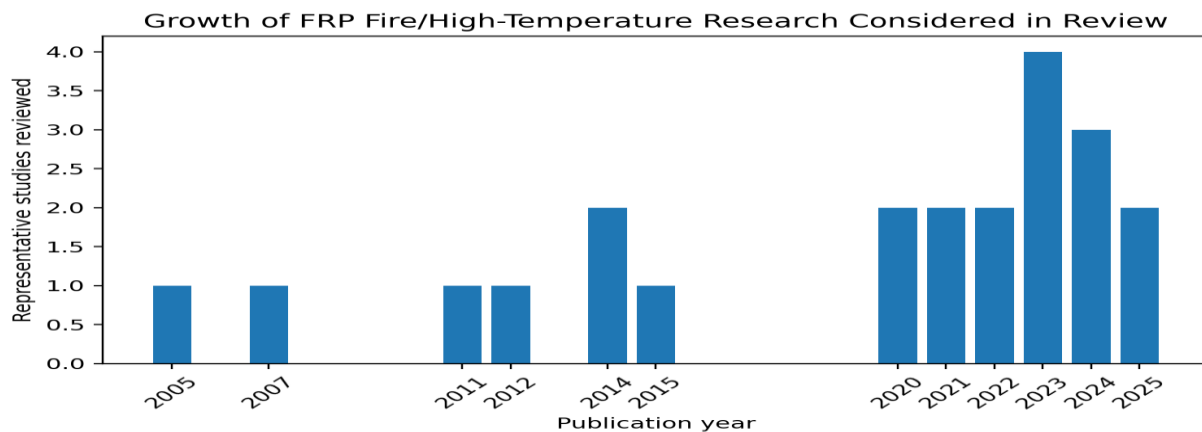


Figure 1. Representative publication trend of reviewed FRP fire/high-temperature studies.

III. THEORETICAL BACKGROUND: FIRE EXPOSURE AND FRP THERMAL DEGRADATION

In structural engineering, a typical temperature-time relationship is often used to represent fire exposure. The ISO 834 curve is represented as $T = 345 \log_{10}(8t$

$+ 1) + 20$, where T is the temperature of the gas (in °C) and t is the time (in minutes). This curve can be useful for comparative testing and numerical benchmarking, but is not representative of the actual compartment fire behaviour, which can vary greatly in terms of fuel load, ventilation, thermal behaviour and cooling phase.

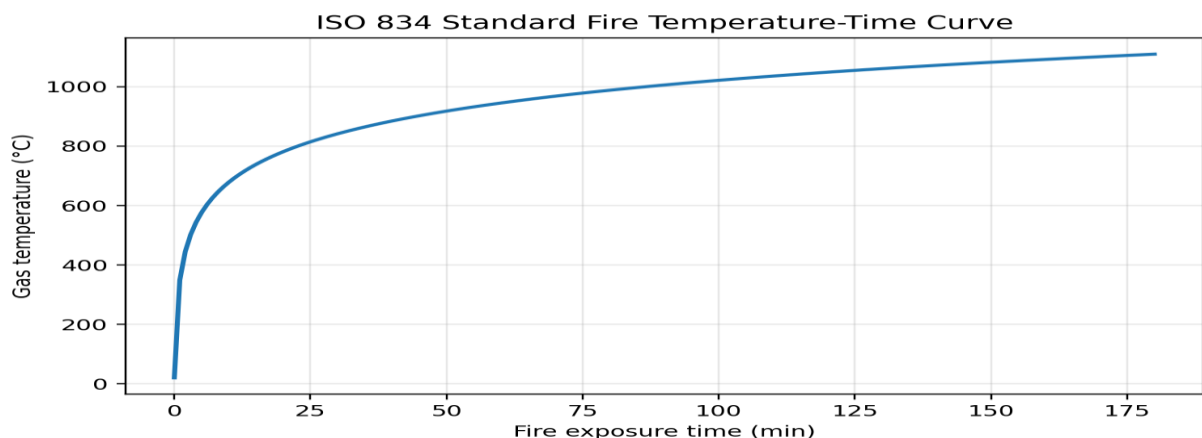


Figure 2. ISO 834 standard fire curve used for thermal exposure modelling.

FRP's controlling degradation mechanism is matrix-controlled. As the temperature approaches T_g , the resin becomes soft, the ability to transfer stiffness through the matrix decreases and the ability to shear transfer at the interface decreases. At temperatures near the decomposition range, the resin becomes discontinuous and loses weight, resulting in significant drops in tensile strength, bond and shear properties.

The reduction in tensile strength is more serious than reduction in elastic modulus in case of GFRP bars because even if the glass fibres are damaged, the remaining old fibres may still contribute to axial (longitudinal) stiffness of GFRP bars, while the stress transfer and anchorage mechanism is significantly damaged.

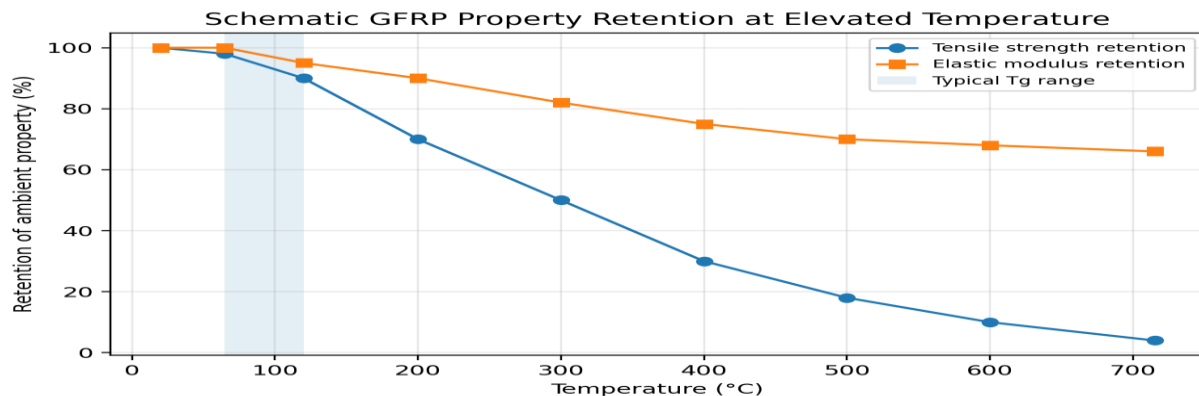


Figure 3. Schematic property retention trend for GFRP bars at elevated temperature, based on trends reported in indexed literature.

IV. LITERATURE SYNTHESIS

4.1 Material-level FRP degradation under elevated temperature

Bazli and Abolfazli reviewed more than one hundred studies on FRP composites under elevated temperatures and showed that mechanical response depends strongly on fibre type, resin system, loading mode and exposure regime. Their overview indicates that degradation accelerates around and above T_g , while strength and modulus loss below T_g is generally less severe. Rosa et al. extended the experimental database for GFRP bars up to 715 °C, showing severe tensile strength reduction at very high temperature while part of the elastic modulus remains because the fibres continue to carry axial stiffness after resin decomposition. Wang et al. similarly emphasized that FRP reinforcing bars degrade differently from steel bars, creating a need for temperature-dependent property models in fire analysis.

For slabs, material degradation is not only a property-reduction issue. Slab capacity relies on bond and anchorage. Therefore, the reduction in FRP tensile capacity must be interpreted together with the temperature profile through the concrete cover and the

ability of unexposed/cool end zones to provide anchorage.

4.2 Concrete cover and heat-transfer protection

The experimental study of the GFRP-reinforced concrete specimens with various concrete cover thickness and concrete strength was experimented by Aydın et al. Based on their results, they are able to conclude that cover thickness is one of the key thermal resistances as it slows down the heat transfer to the embedded FRP, and strength for concrete is comparatively small. This finding is significant to the design of slabs because the depth of the face and cover will affect the temperature history of the FRP bars and thus the time when critical degradation may occur. Numerical fire resistance tests of beams and slabs with FRP can also be seen as illustrating the role of cover. A further cover will give more time to the reinforcement to remain below critical temperatures, resulting in increased fire endurance and minimized growth of early deflections. Excessive cover can lead to greater width of cracks and serviceability issues at ambient conditions, though. Therefore optimization must be done, not just to increase the depth of cover.

4.3 Fire response of FRP-reinforced concrete slabs

Bisby and Kodur argued that the fire endurance of FRP-reinforced slabs must be addressed holistically. Fire resistance is controlled by heat transfer, mechanical response, anchorage, insulation, load level and failure criteria. Nigro et al. performed theoretical and experimental studies on GFRP-reinforced slabs exposed to the ISO 834 standard fire, demonstrating that sufficiently protected anchorage zones may allow fire resistance times exceeding simple predictions based on direct reinforcement temperature alone. Bilotta et al. later developed a three-dimensional finite element model validated against experimental GFRP-RC slab fire tests and used it for parametric analysis covering reinforcement type, boundary restraints and span configurations.

These slab studies collectively show that FRP-RC slab behaviour in fire cannot be judged only by tensile strength reduction curves. Thermal restraint, membrane action, span continuity and boundary condition strongly affect redistribution. Laterally restrained slabs may benefit from arching or tensile membrane action, but this beneficial mechanism may also change cracking and stress concentrations. GFRP and CFRP can show different stiffness retention and failure sequences, while steel-RC maintains a different reserve of ductility.

4.4 Combined fire and impact performance

Zhang et al. addressed a comparatively recent and important issue: low-velocity impact response of GFRP-reinforced concrete slabs after or during elevated temperature exposure. Their validated numerical model considered high-temperature

softening and strain-rate effects for both concrete and FRP bars. It found that high temperature has a significant negative effect on impact resistance, with slabs impacted at high temperature having lower performance than slabs that were cooled after high temperature, and that longer fire duration resulted in more punching damage and displacement. This applies to post-fire assessment, progressive collapse risk and falling debris scenarios.

4.5 FRP-concrete bond and thermal protection systems

When the FRP is used in external bonding, the weak link is the most important, and in the internal FRP reinforcement, it is an important factor. Firmo et al. studied the behaviour of FRP strengthened RC elements in fire and noted that under elevated temperatures, the mechanical and bond properties are affected and therefore these elements should not be used in fire-rated buildings without protection. Performance of fire-protected FRP bonded to concrete was experimentally investigated by Seo et al., which indicated the effect of insulation and system type on the bond capacity loss temperature. Under similar protection, near surface mounted systems can tolerate higher temperatures than externally bonded systems due to the thermal shielding which the concrete groove provides. Proença et al. tested full-scale GFRP-polyurethane composite sandwich floor panels to demonstrate the role of the fire protection boards and air cavities. Although there are differences between sandwich panels and RC slabs, they help provide insight into the vulnerability of the faces and the core material in a sandwich panel, and show that protective layers can significantly improve fire resistance.

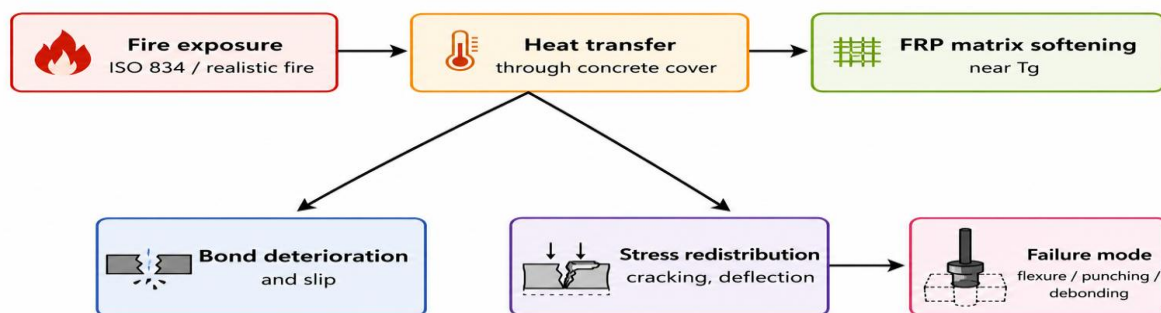


Figure 4. Mechanism map linking fire exposure, heat transfer, FRP degradation, bond loss and slab failure modes.

4.6 Numerical modelling and finite element simulation
The student will investigate numerical modelling and finite element simulation. Full-scale fire tests are costly, time-consuming and parametric limited, and numerical modelling is necessary. Recent studies have progressed from a simpler thermal calculation to three-dimensional sequentially coupled thermal-stress models. Typical modelling tasks involve assigning properties of the concrete and FRP material to the nodes as a function of temperature, transferring the node temperature to the structural analysis, modelling the material nonlinear behaviour (cracking and crushing), and assumptions and comparison of the

modelling results with experimental temperature/deformation data. In the same direction, the dissertation synopsis uploaded here suggests the modelling of FRP composite slabs using ANSYS Workbench with the combined mechanical and thermal loading. It covers geometry generation, meshing, material property definition, static stress loading and results interpretation (principal stress and deformation contour). These preliminary ANSYS results are useful for understanding the effect of model setup and boundary conditions on the stress/deformation fields prior to the completion of the full thermal coupling.

V. COMPARATIVE SUMMARY OF KEY INDEXED STUDIES

Author(s)	Journal	Focus	Key contribution	DOI link
Bisby & Kodur (2007)	Composites Part B	GFRP-RC slabs under standard fire	Holistic fire endurance approach; heat transfer, anchorage and structural response must be considered together.	10.1016/j.compositesb.2006.07.013
Nigro et al. (2012)	Advances in Structural Engineering	GFRP-RC slabs under ISO 834 fire	Experimental and theoretical tests showed the role of cool anchorage and load level in fire resistance.	10.1260/1369-4332.15.4.637
Adelzadeh et al. (2014)	Polymers	Numerical study of FRP-RC slabs	Temperature-induced degradation can cause substantial loss of slab load-carrying capacity.	10.3390/polym6020408
Bellakehal et al. (2014)	Polymers	FRP sheets-reinforced slabs under temperature and sustained load	Sustained load and temperature accelerate deformation and stress redistribution.	10.3390/polym6030873

Firmo et al. (2015)	Composites Part B	FRP-strengthened RC elements review	Fire-rated FRP strengthening needs explicit treatment of property and bond degradation.	10.1016/j.compositesb.2015.10.016
Bilotta et al. (2020)	Engineering Structures	3D FE model of FRP-RC slabs in fire	Validated nonlinear FE model for reinforcement type, boundary condition and span parameters.	10.1016/j.engstruct.2020.111058
Bazli & Abolfazli (2020)	Polymers	FRP materials at elevated temperature	Comprehensive review of tensile, compressive, flexural and shear degradation mechanisms.	10.3390/polym12112600
Seo et al. (2021)	Int. J. Concrete Structures and Materials	Fire-protected FRP-concrete bond	NSM and insulation details control bond survival under high temperature.	10.1186/s40069-020-00448-3
Rosa et al. (2022)	Construction and Building Materials	GFRP tensile behaviour to 715 °C	Tensile strength reduced drastically at high temperature; elastic modulus retained more than strength.	10.1016/j.conbuildmat.2022.126676
Kodur et al. (2023)	Polymers	Fire resistance of beams and slabs with natural FRP	Validated numerical models can compare conventional and bio-based FRP systems.	10.3390/polym15030755
Aydın et al. (2023)	Revista de la Construcción	Cover thickness and concrete strength	Concrete cover thickness is more influential than concrete strength in delaying FRP heating.	10.7764/RDLC.22.1.242

Zhang et al. (2023)	Construction and Building Materials	Fire and low-velocity impact in GFRP slabs	High temperature reduces impact resistance and increases punching damage and displacement.	10.1016/j.conbuildmat.2023.132285
Proença et al. (2021)	Composites Part B	GFRP-polyurethane sandwich floors	Fire protection boards and air cavities substantially improve panel fire resistance.	10.1016/j.compositesb.2021.109171
Proença et al. (2024)	Composite Structures	Composite/hybrid web-core floor panels	Hybrid details and protection strategies modify failure time and thermal degradation.	10.1016/j.compstruct.2024.118071
Machello et al. (2024)	Construction and Building Materials	FRP tensile strength retention review/model	Property retention remains limited until softening range, then declines toward residual capacity.	10.1016/j.conbuildmat.2024.137749

VI. DISCUSSION

6.1 Why FRP composite slabs need separate fire design

- This section discusses why FRP composite slabs require fire design. This section introduces the need of fire design for FRP composite slabs. It is widely shown in the literature that the substitution of steel reinforcement with similar tensile strength in FRPs is not appropriate. FRP bars are also linear-elastic and brittle at ambient temperatures and during a fire, they undergo matrix softening, bond degradation, and possible loss of anchorage. As a result, the complete thermal history should be considered in the fire design, rather than only the ambient design capacity.

6.2 Dominant design parameters

- Concrete cover thickness controls the rate of heat transfer to embedded FRP and is one of the strongest protective parameters in slab systems.

- FRP type governs stiffness, strength retention, thermal expansion mismatch and failure temperature. CFRP may provide higher stiffness, while GFRP is common and cost-effective but temperature-sensitive.
- Boundary restraint and continuity change fire response by enabling or limiting thermal expansion, arching action and membrane action.
- Insulation and fire protection are essential for externally bonded FRP systems because epoxy bond capacity can disappear near or above T_g .
- Cool anchorage length can delay collapse even when exposed reinforcement regions are heated, but it must be modelled explicitly.
- Post-fire residual strength should be assessed separately from strength during fire because cooling may not restore matrix or bond damage.

6.3 Implications for ANSYS-based dissertation modelling

Based on the review, the following conditions should be satisfied by the FE model for this dissertation topic:

(i) The FE model should incorporate transient thermal analysis with the ISO 834 and (if possible) parametric natural fire curves; (ii) The FE model should include temperature dependent properties of concrete (compressive strength, tensile strength, Modulus of elasticity, thermal conductivity and specific heat); (iii) The FE model should include temperature dependent properties of FRP (tensile strength and Modulus of elasticity); (iv) Bond/interface degradation and/or conservative Perfect-bond limitations should be explicitly stated in the FE model; (v) The FE model should use mesh refinement near the heat exposed surfaces, reinforcement and/or supports; and (vi) The FE model should be validated with at least one published slab fire test or numerical benchmark.

VII. RESEARCH GAPS

- 3D-thermo-mechanical models for FRP composite slabs are still less in number than the models of beams and columns.
- Many studies do not consider bond degradation as one of the main failure modes in the fire, assuming perfect bond between the FRP and the concrete material.
- Slab spalling, migration of moisture and loss of concrete cover by explosion are seldom part of routine numerical models.
- Slabs have less post-fire residual capacity after cooling than when exposed to normal fire.
- For hybrid steel-FRP slab systems, further comparative studies are needed since these

systems can provide a compromise in terms of durability and ductility.

- In comparison to ISO 834 exposure, fire and cooling curves for realistic compartments are underutilized.
- There are few probabilistic or reliability-based design guidelines available for FRP-RC slabs in accidental fire and impact situations.
- There continue to be limited experimental validation datasets, particularly for a range of slab thicknesses, reinforcement patterns and boundary conditions.

VIII. PROPOSED FUTURE RESEARCH FRAMEWORK

A publishable research framework should combine literature-based validation, parametric numerical modelling and a transparent design interpretation. First, a baseline FRP-RC slab model should be validated against published fire test results. Second, parametric models should vary FRP type, reinforcement ratio, cover thickness, slab thickness, boundary restraint and fire duration. Third, outputs should include temperature distribution, maximum FRP temperature, mid-span deflection, tensile stress in reinforcement, bond/interface demand, crack initiation zones and failure time. Fourth, results should be benchmarked against steel-RC and hybrid steel-FRP configurations to identify practical advantages and limitations.

Modelling block	Recommended input	Output to report	Publication value
Thermal exposure	ISO 834, natural fire and cooling phase	Temperature at surface, cover and FRP depth	Links fire scenario to property degradation
Material model	Temperature-dependent concrete and FRP properties	Strength/stiffness reduction factors	Improves physical realism
Bond/interface	Perfect bond plus degraded bond sensitivity	Slip, debonding risk or conservative comparison	Addresses major literature gap
Structural response	DL + LL + thermal field	Deflection, stress, cracking zones	Supports design interpretation
Parametric study	Cover, slab thickness, FRP type, restraint	Sensitivity ranking	Provides Scopus-level contribution

IX. CONCLUSION

This review confirms that FRP composite slabs offer strong durability and corrosion-resistance advantages, but their fire performance is governed by polymer matrix degradation, bond deterioration and heat transfer through the concrete cover. Reputed indexed studies show that concrete cover thickness, insulation, anchorage, boundary restraint and FRP type are decisive for fire endurance. Recent numerical studies demonstrate the value of three-dimensional thermo-mechanical finite element modelling, particularly when validated against experimental fire tests. However, reliable prediction of FRP-RC slab behaviour still requires better bond-slip models, realistic fire histories, spalling treatment, residual capacity evaluation and hybrid reinforcement comparisons. For the present dissertation, an ANSYS-based sequential thermal-stress model with validated temperature-dependent material properties and a structured parametric study can provide a meaningful contribution suitable for development into a Scopus-indexed research paper

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