Civil and Sustainable Urban Engineering

Review
Volume 5(2), 2025, 183−194
https://doi.org/10.53623/csue.v5i2.810

Fire Safety and Concrete Performance in Malaysia: A Review of Incidents, Material Behavior, and Standard Testing Protocols

Noorhapsari Ratihi[1]*, Vikram Prasad Sharma[2], Beatrice Achieng Otieno[3]

[1]Fire Safety and Structural Research Unit, Nusantara Engineering Group Berhad, 47500 Subang Jaya, Selangor, Malaysia
[2]Department of Civil Engineering, Visvesvaraya Institute of Technology, India
[3]Department of Civil Engineering, Jomo Kenyatta University of Agriculture and Technology, Kenya

Correspondence: hapsariratihi1@gmail.com

SUBMITTED: 3 September 2025; REVISED: 7 November 2025; ACCEPTED: 16 November 2025

ABSTRACT: Fire incidents remain a critical and persistent challenge in Malaysia, posing significant threats to residential, educational, commercial, and environmental assets. This review synthesizes current knowledge on the Malaysian fire landscape, focusing on the behaviour of concrete structures under elevated temperatures, and examines standard testing protocols essential for assessing material resilience and structural safety. The analysis highlights an alarming frequency of annual fire events, which underscores the urgent need for a coordinated risk management strategy that engages both governmental agencies and private stakeholders. A central theme of the review is the thermo-mechanical performance of concrete, encompassing phenomena such as thermal expansion, spalling, residual compressive and tensile strength, and the effects of prolonged exposure to high temperatures. The study further evaluates the efficacy of material modifications, including fibre reinforcement, geopolymer formulations, and other innovative additives, in enhancing fire resistance and post-fire structural integrity. Additionally, the paper provides a detailed overview of critical international standards, including ASTM and ISO, for the mechanical and durability assessment of concrete after fire exposure, emphasizing their relevance and potential adaptation within the Malaysian context. The review concludes by highlighting the practical implications of these findings: the urgent need for integrated fire safety management, the adoption of advanced fire-resistant concrete technologies, and the enforcement of standardized testing and assessment protocols. Collectively, these strategies are essential to mitigate the devastating impact of fires on Malaysia's built environment, safeguard human life, and ensure long-term structural resilience.

KEYWORDS: Fire incidents; Malaysia; concrete at high temperature; fire resistance; compressive strength; standard testing.

1. Introduction

Fire safety represents a paramount concern for Malaysia's ongoing development and the protection of its citizens, infrastructure, and natural ecosystems. The nation faces a diverse and persistent threat from fire incidents, which occur with alarming regularity across a spectrum of settings. These include densely populated residential buildings, vast forested areas, public educational institutions such as colleges and universities, and industrial waste sites [1, 2]. Each type of incident presents unique challenges and consequences, endangering human lives, causing extensive property damage, and inflicting long-term harm on the environment. The recurring nature of these events underscores an urgent and critical need for robust, effective, and appropriately implemented fire response and control procedures [3, 4].

Research consistently highlights that addressing fire risk in Malaysia requires a concerted, multi-faceted, and cooperative approach. For instance, studies focusing on residential buildings in Selangor have emphasized the indispensable role of collaboration between government agencies, private sector stakeholders, and the Fire and Rescue Department of Malaysia (Bomba) to manage incidents efficiently [5-7]. Similarly, the vulnerability of educational institutions is a growing concern [8]. Research indicates that comprehensive fire safety management techniques are vital to curb the rising number of accidents in public universities, highlighting a gap between policy and practice that needs immediate address [9, 10]. The specific challenges of urban living are exemplified in Kuala Lumpur's low-cost high-rise residences, which are plagued by distinct hazards that demand targeted fire safety protocols and rigorous risk assessments [11].

The environmental dimension of Malaysia's fire problem is equally severe, particularly concerning forest fires. In regions like Pahang, these fires cause significant ecological and economic damage. Modern tools like Google Earth Engine are being leveraged to analyze historical fire hotspots and geographical trends, providing crucial data for better prediction, understanding, and resolution of these environmental incidents. The collective evidence from these studies points to the necessity of thorough risk assessments, effective management systems, and proactive preventive measures nationwide [5, 12]. This review article aims to synthesize this body of knowledge, with a particular focus on the role of construction materials—specifically concrete—in both contributing to and mitigating fire risks, and the standardized methods for evaluating their performance.

2. Fire Incidents in Malaysia: An Overview

The frequency and impact of fire incidents in Malaysia present a worrying and persistent national issue. Empirical data reveals a consistently high number of fires year-on-year, with estimates suggesting approximately 37,000 incidents occur annually. This staggering figure underscores the severity of the situation and the immense pressure placed on emergency services. The ramifications of these fires extend far beyond the immediate destruction of assets. Previous studies showed that the long-term effects are profound, including the displacement of populations, the destruction of livelihoods, and significant, sometimes irreversible, damage to local ecosystems [2, 5]. The high incidence rate is not attributable to a single cause but is rather the product of a complex interplay of socio-economic and infrastructural factors. Key contributors include rapid and often unplanned urbanization patterns, income disparities that limit access to safety measures, ageing or inadequate infrastructure, and a perceived laxity in the enforcement of existing fire safety regulations. This multifaceted problem demands a holistic management strategy [13, 14]. Research into residential colleges further reinforces that proactive, rather than reactive, fire safety procedures are essential for safeguarding occupants, particularly in high-density accommodations like student housing. The overarching conclusion is that mitigating Malaysia's fire challenge requires a systemic approach that addresses these root causes through stringent policy, improved infrastructure, and continuous public education [14, 15]. Major fire incidents in Malaysia with date, location, type, and key notes on impact/cause is shown in Table 1.

Table 1. Major fire incidents in Malaysia.

Location	Incident	Brief notes (impact/cause)	Reference
Sungai Buloh, Selangor	Bright Sparklers fireworks factory disaster	Catastrophic fire and explosions at a pyrotechnics facility; major fatalities and injuries; widely cited Malaysian industrial disaster case.	[16]
Johor Bahru, Johor	Sultanah Aminah Hospital ICU fire	Hospital intensive care unit blaze with multiple fatalities; highlighted electrical safety, oxygen-enriched environment hazards, and emergency response issues.	[17]
Kuala Lumpur	Campbell Shopping Complex fire	Landmark commercial-building fire in KL's city center; frequently referenced in urban disaster/risk literature for KLC.	[18]
Johor (Johor Port / Petronas terminal)	Storage-tank / sand-warehouse fires	Industrial fires involving petroleum storage; reported loss of multiple tanks and large fuel volumes; used as Malaysian case examples in process safety discourse.	[19]
Kemaman, Terengganu	Kemaman Bitumen Company (KBC) plant fire	Major industrial facility fire; highlighted emergency response and risk management gaps in a coastal industrial hub.	[20]
West Malaysia	Refinery fire case study	Detailed causal analysis of a refinery fire; lessons on MHI (major-hazard installation) management, design/operations failures, and emergency response.	[21]

3. Concrete Behaviour at Elevated Temperature

3.1. Thermal expansion and contraction.

Concrete, while renowned for its durability, undergoes significant and potentially detrimental changes when exposed to high temperatures, compromising structural integrity (Table 2). A fundamental aspect of this behaviour is thermal expansion and contraction. As concrete is heated, its constituent materials expand, inducing internal stresses that can lead to microcracking and volumetric changes. Upon cooling, the subsequent contraction can cause further cracking or even catastrophic failure if not properly accounted for in the design phase. The degree of expansion and contraction is influenced by the concrete's mix design, aggregate type, and moisture content [21–23]. Research has explored material modifications to mitigate these adverse effects. Incorporating mineral admixtures like fly ash or silica fume can enhance thermal stability by reducing the likelihood of explosive spalling and improving performance under heat. Furthermore, sustainable concrete mixes utilizing recycled materials have shown promising fire resistance, aligning green building goals with enhanced safety standards. The use of polypropylene fibres has proven particularly effective; these fibres melt at high temperatures, creating pathways for moisture vapour to escape and thereby reducing internal pore pressure, which minimizes spalling and mitigates cracking from thermal stresses. Understanding these mechanisms is crucial for designing fire-resistant structures [24, 25].

3.2. Structural design considerations.

The behaviour of concrete during fire events is a critical design consideration, as it directly affects structural safety and occupant protection. Post-fire assessment techniques play a vital role in determining the extent of damage, residual mechanical properties, and the overall safety of affected structures. Such assessments inform crucial decisions regarding repair, strengthening, or demolition of fire-damaged buildings. Comparative studies of different concrete types—including high-strength concrete (HSC), normal-strength concrete (NSC), and innovative alternatives such as geopolymer concrete—have provided valuable insights into their performance under elevated temperatures [25, 26].

High-strength concrete, while exhibiting superior compressive strength under normal conditions, is more prone to explosive spalling during rapid heating due to its lower permeability and dense microstructure, which can trap moisture and generate high internal vapour pressures. In contrast, normal-strength concrete tends to have slightly better fire performance due to its more porous structure, which allows gradual release of vapour and reduces spalling risk. Geopolymer concrete, composed of aluminosilicate binders rather than traditional Portland cement, demonstrates exceptional fire resistance. Its inherent non-flammability, low thermal conductivity, minimal shrinkage, and reduced spalling susceptibility contribute to superior residual mechanical properties following high-temperature exposure. These characteristics make geopolymer concrete a highly promising material for infrastructure in fire-prone regions.

Understanding the differences in thermal behaviour among these concrete types is essential for developing fire-resilient structural designs. Design strategies must consider not only the compressive and tensile performance of the material under heat but also the likelihood of spalling, cracking, and overall deformation of beams, columns, and slabs. Integrating advanced materials like geopolymer concrete into structural systems, alongside optimized reinforcement detailing and protective coatings, can significantly enhance the fire resistance of buildings. Ultimately, a comprehensive design approach that accounts for material-specific fire behaviour, element-level performance, and innovative construction technologies is critical to ensuring life safety and maintaining structural integrity during and after fire events [27–29].

Table 2. Concrete behaviour at elevated temperature.

Subsection	Key Aspects	Details	Reference
Thermal Expansion and Contraction	Mechanism	Heating causes expansion of cement paste and aggregates, leading to internal stresses, microcracking, and volumetric instability. Cooling contraction may worsen cracking or cause failure.	[21-24]
	Mitigation with mineral admixtures	Fly ash, silica fume, and similar admixtures reduce explosive spalling and enhance thermal stability.	
	Sustainable mixes	Recycled aggregates and green concretes improve fire resistance while supporting sustainable construction.	
	Fibres	Polypropylene fibres melt at high temperatures, creating channels for vapour release, reducing pore pressure and spalling.	
Structural Design Considerations	Post-fire assessment	Critical for determining whether repair or demolition is necessary after fire exposure.	[25-29]
	Concrete type comparisons	HSC, NSC, and geopolymer concretes evaluated under high-temperature loading.	
	Fire resistance of elements	Beams, columns, and walls studied for spalling, residual strength, and fire endurance.	
	Geopolymer concrete	Offers superior high-temperature performance, non-flammability, and low smoke production compared to OPC.	

4. Post-Fire Mechanical Properties of Concrete

4.1. Compressive strength.

The residual compressive strength of concrete is a primary indicator of its post-fire structural capacity (Table 3). Experimental data reveals a clear relationship between exposure temperature and strength loss. Concrete typically retains its structural integrity (with a reduced safety factor) up to approximately 350°C. At around 500°C, a noticeable loss in strength occurs, often necessitating minor repairs. However, at 650°C and beyond, concrete suffers severe damage characterized by rapid degradation, often requiring extensive replacement of the affected elements [30]. The duration of exposure further exacerbates the damage. The type of concrete significantly influences its performance. High-strength concrete (HSC), despite its initial superior strength, often exhibits more pronounced strength loss at high temperatures compared to normal-strength concrete (NSC). This is attributed to its denser microstructure and higher paste content, which lead to greater thermal incompatibility between the paste and aggregates, resulting in increased microcracking [31]. The quality and grade of the concrete are therefore critical factors in determining its ability to withstand thermal insult, guiding both design choices and post-fire assessment protocols.

4.2. Tensile and flexural strength.

The tensile properties of concrete are even more sensitive to high temperatures than its compressive strength. The splitting tensile strength, for instance, can drop to just 16.9% of its original value after exposure to 1000°C [32]. The dense nature of concrete promotes heat stress, leading to extensive microcracking, primarily due to the decomposition of chemical compounds like Portlandite ($Ca(OH)_2$). These cracks not only reduce the effective cross-sectional area but also widen under tensile stress, leading to a more dramatic reduction in tensile capacity. Similarly, the residual flexural strength of concrete experiences a severe decline upon heating. This drop is often more significant than the loss in compressive strength, especially after prolonged exposure [33]. The degradation is driven by microcracking, shrinkage cracks from water loss, and the breakdown of the bond between the cement paste and aggregates. This heightened sensitivity of tensile and flexural properties is a critical consideration for structural elements like beams and slabs, which are subject to bending stresses, and must be carefully evaluated in any post-fire forensic investigation.

Table 3. Post-Fire mechanical properties of concrete.

Subsection	Key Aspects	Details	Reference
Compressive Strength	Temperature effect	Retains strength (with reduced safety factor) up to ~350 °C; noticeable strength loss at ~500 °C (minor repairs); severe degradation beyond 650 °C requiring replacement. Duration of fire exposure further worsens damage.	[30]
	Concrete type	High-strength concrete (HSC) shows greater strength loss than normal-strength concrete (NSC) due to denser microstructure and thermal incompatibility, leading to more microcracking.	[31]
Tensile Strength	Splitting tensile strength	Highly sensitive to heat. At 1000 °C, residual splitting tensile strength drops to ~16.9% of original capacity due to microcracking and decomposition of $Ca(OH)_2$.	[32]
Flexural Strength	Residual flexural strength	Experiences sharply decline than compressive strength, particularly after prolonged heating. Degradation caused by microcracking, water loss shrinkage, and weakened paste–aggregate bond.	[33]

5. Assessment of Mechanical Properties

5.1. Standard mechanical tests.

5.1.1. Compressive strength test: ASTM C39, ISO 1920-4.

The compressive strength test is the most fundamental and widely adopted method to evaluate the load-bearing capacity of cementitious composites and concrete (Table 4). According to ASTM C39 and ISO 1920-4 standards, the test involves applying a steadily increasing compressive load to cylindrical or cubical specimens until failure occurs. This property directly reflects the material's ability to resist structural loads and is often considered the key parameter for quality control and design validation. The procedure requires specimens to be cured under controlled conditions before testing, ensuring hydration and microstructural development reach a representative stage. Factors such as specimen geometry, loading rate, curing method, and age at testing significantly influence results, hence standardization is critical. For innovative or modified concrete materials, such as those incorporating supplementary cementitious materials, recycled aggregates, or fibers, compressive strength testing provides baseline performance data compared to conventional mixes. Beyond ultimate load capacity, failure modes—such as brittle fracture or gradual crushing—offer insights into structural safety and ductility. In practice, compressive strength is used to classify concrete grades, establish mix designs, and ensure compliance with codes. While highly indicative of structural capacity, it does not capture other performance aspects such as tensile behavior, durability, or fire resistance, necessitating complementary tests. Nonetheless, compressive strength remains the cornerstone property for construction materials, guiding both engineering applications and durability predictions [34, 35].

5.1.2. Tensile strength test: splitting (ASTM C496) vs. flexural (ASTM C78).

Tensile strength is critical for evaluating crack resistance, serviceability, and long-term durability of concrete, as the material is inherently weak in tension. Two standardized methods are primarily used: the splitting tensile test (ASTM C496) and the flexural test (ASTM C78). The splitting tensile test involves loading a cylindrical specimen along its diameter, generating indirect tension through compressive forces applied at opposite sides. This method is relatively simple, requires smaller specimens, and provides a direct measure of tensile resistance. However, it may not fully represent actual field stress conditions. Conversely, the flexural test measures the modulus of rupture by applying a load on a beam specimen until failure. This method better simulates tensile stresses in structural elements such as pavements and slabs, where bending governs performance. Flexural strength is generally higher than splitting tensile strength due to stress distribution, but it also exhibits greater variability, being sensitive to specimen geometry, surface flaws, and loading configuration. Selection between the two methods depends on intended applications: splitting tests are favored for material characterization and quality control, while flexural tests are more relevant for design and performance prediction in structural elements. For advanced concretes containing fibers or nano-modifications, tensile assessments also provide insights into crack-bridging capabilities and post-cracking behavior. Despite inherent variability, tensile strength tests complement compressive testing by revealing failure initiation mechanisms and ensuring structural integrity under complex stress conditions [36, 37].

5.2. Standard durability and fire tests.

5.2.1. Durability indicator: water absorption test (ASTM C642).

Durability is a vital property of cementitious materials, as it dictates resistance to environmental degradation over the service life of structures. The water absorption test, standardized by ASTM C642, evaluates the porosity and permeability of hardened concrete by measuring the increase in mass when specimens are immersed in water under controlled conditions. This test provides an indirect indicator of microstructural quality, as higher absorption typically correlates with greater pore connectivity, reduced density, and higher susceptibility to aggressive agents such as chlorides, sulfates, and carbon dioxide. In practice, specimens are oven-dried to constant mass, cooled, and then immersed in water for predetermined intervals. The difference between dry and saturated weights quantifies water absorption and apparent porosity. Lower absorption values generally signify higher durability, particularly for concretes exposed to marine environments, freeze-thaw cycles, or chemical attack. This method is especially valuable for assessing performance of modified concretes incorporating pozzolanic materials, polymeric admixtures, or fibers that aim to reduce porosity and enhance impermeability. While the test does not directly measure resistance to specific deterioration mechanisms, it serves as a reliable durability indicator and comparative tool across different mixtures. Moreover, results are frequently correlated with service-life models and predictive frameworks. Limitations include the inability to capture microcrack propagation under load or long-term transport phenomena; therefore, the test is often combined with chloride permeability or accelerated aging methods. Overall, ASTM C642 remains a cost-effective and standardized approach for benchmarking concrete durability [38].

5.2.2. Direct Fire Resistance: Standard Furnace Tests (ASTM E119, ISO 834-1).

Fire resistance is an essential performance parameter for construction materials, ensuring safety, structural integrity, and life protection in fire-prone scenarios. Standardized furnace tests, governed by ASTM E119 and ISO 834-1, evaluate fire resistance by subjecting specimens to controlled heating curves that simulate real fire conditions. In these tests, structural elements such as walls, slabs, or columns are exposed to elevated temperatures in a furnace while critical performance metrics such as load-bearing capacity, thermal insulation, and integrity, are monitored. The time duration until failure or loss of function determines the fire-resistance rating, often expressed in hours. For concrete, fire performance is influenced by composition, aggregate type, moisture content, and presence of supplementary materials or fibers. High-strength concretes, while mechanically superior, may exhibit explosive spalling under rapid heating due to pore pressure build-up, necessitating mitigation strategies such as polypropylene fibers. Furnace testing provides realistic insights into thermal gradients, deformation, cracking, and residual strength after exposure. ASTM E119 focuses on endurance ratings for structural members, while ISO 834-1 specifies the time-temperature curve and general testing framework, ensuring comparability across studies and codes. These tests are critical for compliance with building safety regulations, fire design codes, and risk assessment in high-rise or industrial facilities. Although costly and time-consuming, furnace tests remain the benchmark for evaluating fire performance, complementing small-scale thermal analysis or simulation models. Ultimately, direct fire resistance testing ensures that structural materials not only meet load-bearing expectations but also safeguard occupants and infrastructure during extreme thermal events [39, 40].

Table 4. Standard mechanical, durability, and fire tests for concrete.

Subsection	Test Method	Key Assessment Parameters	Practical Applications	Limitations	Reference
Compressive Strength Test	ASTM C39; ISO 1920-4	• Load-bearing capacity via steadily increasing compressive load. • Failure mode: brittle fracture or gradual crushing. • Influenced by specimen size, curing, and age.	• Quality control and classification of concrete grades. • Benchmark for mix design and code compliance. • Comparative baseline for modified concretes (e.g., SCMs, fibers).	• Does not capture tensile, durability, or fire performance. • Sensitive to curing and geometry variations.	[34, 35]
Tensile Strength Test	Splitting Tensile: ASTM C496; Flexural Strength: ASTM C78	• Splitting test: indirect tensile resistance using cylindrical specimens. • Flexural test: modulus of rupture under beam bending. • Sensitive to geometry, loading rate, and surface flaws.	• Splitting test: material characterization and QC. • Flexural test: design validation for slabs, pavements, beams. • Insight into crack initiation and post-cracking response for fiber concretes.	• Splitting test: does not replicate field tensile stresses. • Flexural test: higher variability, sensitive to flaws and geometry.	[36, 37]
Durability Indicator: Water Absorption Test	ASTM C642	• Measures porosity and permeability by comparing dry and saturated mass. • Provides apparent porosity as durability index.	• Benchmark for long-term resistance against marine exposure, freeze-thaw cycles, and chemical attack. • Evaluates modified concretes (SCMs, polymers, fibers). • Useful for predictive service-life modeling.	• Does not capture microcrack propagation under load. • Limited in representing transport of chlorides/sulfates. • Often paired with chloride permeability tests.	[38]
Direct Fire Resistance: Standard Furnace Tests	ASTM E119; ISO 834-1	• Exposes walls, slabs, or columns to standardized heating curve. • Measures load-bearing, thermal insulation, and integrity. • Failure time gives fire-resistance rating (hours).	• Ensures compliance with fire codes and safety standards. • Evaluates spalling, cracking, deformation, and residual strength. • Essential for high-rise and industrial fire risk assessments.	• Costly and time-consuming. • Requires full-scale testing. • Results vary with moisture and mix composition.	[39, 40]

6. Implication in Malaysia

Fire incidents in Malaysia have underscored the urgent need to integrate material performance with robust safety regulations [2]. Concrete, as the primary construction material, offers inherent fire resistance due to its low thermal conductivity and non-combustibility. However, its actual performance depends on specific properties discussed such as compressive and tensile strength, porosity, and durability, and their verification through standardized testing. For instance, compressive and tensile strength tests establish baseline structural reliability, while water absorption and furnace fire resistance tests provide critical insights into long-term resilience under extreme conditions. These assessments are directly relevant to mitigating recurring fire incidents , as they ensure that materials used in buildings can withstand both structural loads and sudden thermal exposure without catastrophic failure [41, 42].

Despite the availability of standards such as ASTM and ISO, the Malaysian construction industry still faces gaps in application and enforcement. Building codes may reference international fire-resistance requirements, but compliance checks and post-construction audits are often limited. Furthermore, adoption of advanced fire-resilient concretes such as fiber-reinforced or geopolymer concretes, remains low, largely due to higher costs, limited technical expertise, and fragmented awareness among stakeholders. This gap results in a reliance on conventional concrete mixes that may not provide adequate safety in high-risk structures such as high-rise apartments, hospitals, and industrial complexes [43, 44]. Addressing these challenges requires a dual strategy. First, policy and enforcement mechanisms must be strengthened to ensure uniform compliance with fire-safety codes, backed by rigorous inspection and penalties for negligence. Second, advancements in material science and engineering should be promoted through research funding, pilot projects, and industry training to encourage the use of innovative fire-resilient materials. By aligning policy enforcement with material innovation, Malaysia can transition toward a more resilient construction landscape, reducing fire risks while ensuring public safety [45–47].

6. Conclusion and Future Perspectives

The review highlights the critical and complex challenges posed by fire incidents in Malaysia, often exacerbated by socio-economic pressures and gaps in safety regulation. The frequency of annual fires emphasizes the urgent need for coordinated, proactive fire risk management across all relevant stakeholders. Regarding construction materials, concrete despite its inherent strength experiences notable deterioration in mechanical properties, including compressive, tensile, and flexural strength, under high-temperature exposure. This behaviour is influenced by multiple factors, such as thermal expansion, the specific type of concrete (HSC versus NSC), and the incorporation of material modifications. The integration of fibres and advanced materials like geopolymer concrete presents a promising avenue for enhancing the fire resistance of future structures. Furthermore, the recovery of properties after fire is possible but limited, emphasizing the importance of rigorous post-fire assessment using standardized tests (ASTM, ISO) for compressive strength, permeability, and overall durability. Moving forward, Malaysia's strategy should be twofold: first, to aggressively implement improved fire prevention and management policies across all sectors, and second, to embrace and mandate the use of fire-resistant concrete technologies and rigorous standardized evaluation in design and construction practices to build a more resilient and safer built environment.

Author Contributions

All aspects of the review article, including conceptualization, methodology, investigation, writing original draft, writing review and editing, and visualization, were carried out sby N. Ratihi.

Competing Interest

The authors declare no conflict of interest.

Data Availability

The data presented in this study are available on request from the corresponding author.

Reference

[1] Musarat, M.A.; Alaloul, W.S.; Irfan, M.; Sreenivasan, P.; Rabbani, M.B.A. (2023). Health and Safety Improvement through Industrial Revolution 4.0: Malaysian Construction Industry Case. *Sustainability*, *15*, 201. https://doi.org/10.3390/su15010201.

[2] Wan Jusoh, W.N.; Tharima, A.F.; Ghani, W.; Mohamad Lukman, N.H.; Visvasathan, S.; Shamsudin, M.H.; Mahmud Zuhudi, N.Z.; Mohd Nur, N. (2023). Initial Assessment of Fire Response Time between Different Categories of Fire Stations in Malaysia. *Fire*, *6*, 6. https://doi.org/10.3390/fire6010006.

[3] Wang, W.; Su, Y.; Cao, H.; Li, D. (2025). Enhancing Chemical Laboratory Safety with Hazards Risks Mitigation and Strategic Actions. *Laboratories*, *2*, 5. https://doi.org/10.3390/laboratories2010005.

[4] Qin, R.; Zhang, X.; Shi, C.; Zhao, Q.; Yu, T.; Xiao, J.; Liu, X. (2025). Identifying Critical Fire Risk Transmission Paths in Subway Stations: A PSR–DEMATEL–ISM Approach. *Fire*, *8*, 332. https://doi.org/10.3390/fire8080332.

[5] Chew, Y.J.; Ooi, S.Y.; Pang, Y.H.; Wong, K.-S. (2022). A Review of Forest Fire Combating Efforts, Challenges and Future Directions in Peninsular Malaysia, Sabah, and Sarawak. *Forests*, *13*, 1405. https://doi.org/10.3390/f13091405.

[6] Kumaresen, M.; Teo, F.Y.; Selvarajoo, A.; Sivapalan, S.; Falconer, R.A. (2025). Assessing Community Perception, Preparedness, and Adaptation to Urban Flood Risks in Malaysia. *Water*, *17*, 2323. https://doi.org/10.3390/w17152323.

[7] Manan, N.; Abu Hasan, N.I.; Hasan, A.; Mariyah, N.; Abdul Ghafar, N.M.; Jamal, N.F. (2020). Fire Risk Assessment of Residential Buildings Based on Fire Statistics from Selangor. *Journal of Pharmaceutical and Scientific Innovation*, vii.

[8] Hoffmann, R.; Blecha, D. (2020). Education and Disaster Vulnerability in Southeast Asia: Evidence and Policy Implications. *Sustainability*, *12*, 1401. https://doi.org/10.3390/su12041401.

[9] Qin, R.; Shi, C.; Yu, T.; Ding, C.; Ren, X.; Xiao, J. (2024). Analysis of Factors Influencing Fire Accidents in Commercial Complexes Based on WSR-DEMATEL-ISM Model. *Fire*, *7*, 224. https://doi.org/10.3390/fire7070224.

[10] Masoumi, Z.; van L. Genderen, J.; Maleki, J. (2019). Fire Risk Assessment in Dense Urban Areas Using Information Fusion Techniques. *ISPRS International Journal of Geo-Information*, *8*, 579. https://doi.org/10.3390/ijgi8120579.

[11] Akashah, F.W.; Baaki, K.; Lee, S. (2017). Fire Risk Assessment of Low Cost High Rise Residential Buildings in Kuala Lumpur: A Case Study. *Journal of Design and Built Environment*, *17*, 124–139. https://doi.org/10.22452/jdbe.sp2017no1.11.

[12] Singh, H.; Srivastava, P.K.; Prasad, R.; Srivastava, S.K. (2025). Tracking Post-Fire Vegetation Regrowth and Burned Areas Using Bitemporal Sentinel-1 SAR Data: A Google Earth Engine Approach in Heath Vegetation of Mooloolah River National Park, Queensland, Australia. *Remote Sensing*, *17*, 2031. https://doi.org/10.3390/rs17122031.

[13] Twigg, J.; Christie, N.; Haworth, J.; Osuteye, E.; Skarlatidou, A. (2017). Improved Methods for Fire Risk Assessment in Low-Income and Informal Settlements. *International Journal of Environmental Research and Public Health*, *14*, 139. https://doi.org/10.3390/ijerph14020139.

[14] Wang, X.; Zhao, H.; Zhang, Z.; Yin, Y.; Zhen, S. (2023). The Relationship between Socioeconomic Factors at Different Administrative Levels and Forest Fire Occurrence Density Using a Multilevel Model. *Forests*, *14*, 391. https://doi.org/10.3390/f14020391.

[15] Mohamed Yusof, N.F.; Mohd Roshdi, F.R.; Saharuddin, S.; Mohd Noor, S.N.A. (2021). Fire Safety Management in Malaysian Higher Educational Institutions. *International Journal of Real Estate Studies*, *15*(S1), 70–81. https://doi.org/10.11113/intrest.v15nS1.118.

[16] Shaluf, I.M.; Ahmadun, F.; Mustapha, S.; Mat Said, A.; Sharif, R. (2002). Bright Sparklers Fire and Explosions: The Lessons Learned. *Disaster Prevention and Management*, *11*, 214–221. https://doi.org/10.1108/09653560210435812.

[17] Salvaraji, L.; Jeffree, M.S.; Awang Lukman, K.; Saupin, S.; Avoi, R. (2022). Electrical Safety in a Hospital Setting: A Narrative Review. *Annals of Medicine and Surgery*, *78*, 103781. https://doi.org/10.1016/j.amsu.2022.103781.

[18] Aman, A.J.; Ng, C.P.; Wong, M.M.R.; Rofi, M.F.; Ahmad, N.; Abas, F.; Law, T.H. (2025). Mapping Disaster Hazards and Risks—A Case Study in Kuala Lumpur City (KLC). *Jurnal Kejuruteraan*, *37*, 421–431. https://doi.org/10.17576/jkukm-2025-37(1)-29.

[19] Abd Rahman, A.; Rahim, Z.A.; Zaidi, A.M.A.; Zaki, S.A.; Ahmad, S.S. (2019). Fire Incident Toward Peninsular Malaysia's Industrial Area: A Case Study of Terengganu. *Key Engineering Materials*, *797*, 127–134. https://doi.org/10.4028/www.scientific.net/KEM.797.127.

[20] Shaluf, I.M.; Ahmadun, F.; Mat Said, A. (2003). Fire Incident at a Refinery in West Malaysia: The Causes and Lessons Learned. *Journal of Loss Prevention in the Process Industries*, *16*, 297–303. https://doi.org/10.1016/S0950-4230(03)00021-4.

[21] Malik, S.; Bhattacharyya, S.K.; Barai, S.V. (2021). Elevated Temperature and Fire Damage in Concrete: Microstructure, Properties and Assessment. *Construction and Building Materials*, *278*, 122347. https://doi.org/10.1016/j.conbuildmat.2021.122347.

[22] Bazli, M.; Abolfazli, M. (2020). Mechanical Properties of Fibre Reinforced Concrete at Elevated Temperatures. *Journal of Building Engineering*, *32*, 101578. https://doi.org/10.1016/j.jobe.2020.101578.

[23] Memon, S.A.; Cui, H.; Lo, T.Y.; Barbhuiya, S. (2019). Development of Sustainable Concrete Using Recycled Aggregates. *Sustainability*, *11*, 1214. https://doi.org/10.3390/su11051214.

[24] Ye, G.; De Schutter, G.; Taerwe, L. (2012). Influence of Polypropylene Fibres on Concrete at Elevated Temperature. *Cement and Concrete Research*, *42*, 71–81. https://doi.org/10.1016/j.cemconres.2011.08.002.

[25] Bala Jovanović, I.; Mitrović, A.; Zejak, R.; Đurović, A. (2021). Post-Fire Behaviour of Reinforced Concrete Structures. *Engineering Structures*, *233*, 111902. https://doi.org/10.1016/j.engstruct.2020.111902.

[26] Shah, S.N.R.; Akashah, F.W.; Shafigh, P. (2019). Fire Performance of High-Strength and Geopolymer Concrete: A Comparative Review. *Journal of Building Engineering*, *26*, 100914. https://doi.org/10.1016/j.jobe.2019.100914.

[27] Amran, Y.H.M.; Alyousef, R.; Alabduljabbar, H.; Alaskar, A.; Alrshoudi, F. (2020). Fire Resistance of Geopolymer Concrete: A Review. *Construction and Building Materials*, *260*, 119654. https://doi.org/10.1016/j.conbuildmat.2020.119654.

[28] Almeshal, I.; Abu Bakar, S.; Tayeh, B.A. (2022). Spalling Behaviour of Concrete Structures under Fire: A Review. *Structures*, *39*, 994–1009. https://doi.org/10.1016/j.istruc.2022.03.092.

[29] Roviello, G.; Ricciotti, L.; Ferone, C.; Colangelo, F.; Tarallo, O. (2015). Fire Resistant Geopolymer Composites: Up-to-Date Review and Perspectives. *Ceramics International*, *41*, 7304–7311. https://doi.org/10.1016/j.ceramint.2015.02.148.

[30] Mundhada, A.R.; Pofale, A.D. (2015). Effect of Elevated Temperature on Compressive Strength of Concrete. *International Journal of Engineering Research and Applications*, *5*, 38–42. https://doi.org/10.9790/9622-0507043842.

[31] Kumar Poloju, S.; Rahul Rollakanti, M. (2018). Performance of High Strength Concrete at Elevated Temperatures. *International Journal of Civil Engineering and Technology*, *9*, 832–840. https://doi.org/10.13140/RG.2.2.19004.49288.

[32] Thelandersson, S. (1972). Effect of High Temperature on Tensile Strength of Concrete. *Materiaux et Constructions*, *5*, 351–356. https://doi.org/10.1007/BF02473999.

[33] Aydın, S.; Baradan, B. (2007). Effect of High Temperature on Flexural Strength of Concrete Incorporating Silica Fume. *Cement and Concrete Research*, *37*, 220–227. https://doi.org/10.1016/j.cemconres.2006.10.009.

[34] ASTM C39/C39M-23. (2023). Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens. ASTM International: West Conshohocken, PA, USA. https://doi.org/10.1520/C0039_C0039M-23.

[35] ISO 1920-4:2005. (2005). Testing of Concrete—Part 4: Strength of Hardened Concrete. International Organization for Standardization: Geneva, Switzerland.

[36] ASTM C496/C496M-23. (2023). Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens. ASTM International: West Conshohocken, PA, USA. https://doi.org/10.1520/C0496_C0496M-23.

[37] ASTM C78/C78M-22. (2022). Standard Test Method for Flexural Strength of Concrete. ASTM International: West Conshohocken, PA, USA. https://doi.org/10.1520/C0078_C0078M-22.

[38] ASTM C642-21. (2021). Standard Test Method for Density, Absorption, and Voids in Hardened Concrete. ASTM International: West Conshohocken, PA, USA. https://doi.org/10.1520/C0642-21.

[39] ASTM E119-22. (2022). Standard Test Methods for Fire Tests of Building Construction and Materials. ASTM International: West Conshohocken, PA, USA. https://doi.org/10.1520/E0119-22.

[40] ISO 834-1:1999. (1999). Fire-Resistance Tests—Elements of Building Construction—Part 1: General Requirements. International Organization for Standardization: Geneva, Switzerland.

[41] Sudarisman, S.; Haniel, H.; Taufik, A.K.; Tiopan, M.; Himarosa, R.A.; Muflikhun, M.A. (2023). Tensile, Compressive, and Flexural Characterization of CFRP Laminates Related to Water Absorption. *Journal of Composites Science*, *7*, 184. https://doi.org/10.3390/jcs7050184.

[42] Xu, Z.; Yang, L.; Du, X.; Li, Z.; Yang, Z.; Jia, X.; He, Y. (2021). Fire Resistance and Seismic Performance Study of a High-Strength Construction Steel Using Creep and Internal Friction Analysis. *Metals*, *11*, 1045. https://doi.org/10.3390/met11071045.

[43] Musarat, M.A.; Alaloul, W.S.; Cher, L.S.; Qureshi, A.H.; Alawag, A.M.; Baarimah, A.O. (2023). Applications of Building Information Modelling in the Operation and Maintenance Phase of Construction Projects: A Framework for the Malaysian Construction Industry. *Sustainability*, *15*, 5044. https://doi.org/10.3390/su15065044.

[44] Alaloul, W.S.; Musarat, M.A.; Rabbani, M.B.A.; Iqbal, Q.; Maqsoom, A.; Farooq, W. (2021). Construction Sector Contribution to Economic Stability: Malaysian GDP Distribution. *Sustainability*, *13*, 5012. https://doi.org/10.3390/su13095012.

[45] Batool, F.; Mohsin, M.; Alwadi, B.M. (2025). Green Innovation and Environmental Performance: The Moderating Roles of Governance and Policy. *World*, *6*, 29. https://doi.org/10.3390/world6010029.

[46] Khatoon, U.T.; Velidandi, A. (2025). An Overview on the Role of Government Initiatives in Nanotechnology Innovation for Sustainable Economic Development and Research Progress. *Sustainability*, *17*, 1250. https://doi.org/10.3390/su17031250.

[47] Yew, P.J.; Chaulagain, D.; Same, N.N.; Park, J.; Lim, J.-O.; Huh, J.-S. (2024). Optimal Hybrid Renewable Energy System to Accelerate a Sustainable Energy Transition in Johor, Malaysia. *Sustainability*, *16*, 7856. https://doi.org/10.3390/su16177856.