UNIVERSITI TEKNOLOGI MARA

BEHAVIOUR OF CARBON FIBRE REINFORCED POLYMER (CFRP) STRENGTHENED REINFORCED CONCRETE COLUMN INSULATED WITH COMPOSITE EXPOSED TO ELEVATED TEMPERATURE

AFIFUDIN BIN HABULAT

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ABSTRACT

Various types of cementitious composites (CCs) have been developed and examined under elevated temperature conditions, however, their potential application as composite insulation (CI) for structural fire protection remains scarcely explored. This significant research gap has motivated the present study, which focuses on developing and assessing the effectiveness of CI fabricated from CC in enhancing fire resistance of reinforced concrete (RC) members. In this study, the influence of elevated temperatures on the mechanical and non-destructive properties of CI was investigated. The CI mixtures were composed of ordinary Portland cement (OPC), ground granulated blast furnace slag (GGBS), silica sand (SS), expanded perlite aggregates (EPA), and polypropylene (PP) fibres. The mechanical tests included residual compressive strength (RCS), residual flexural strength (RFS), and residual tensile strength (RTS), while the non-destructive assessments were conducted using Rebound Hammer (RH) and Ultrasonic Pulse Velocity (UPV) tests. In addition, the thermal and microstructural characteristics of CI were evaluated through thermal conductivity (TC), thermogravimetric analysis (TG), differential scanning calorimetry (DSC), X-ray diffraction (XRD), and scanning electron microscopy (SEM). Six (6) mixes, namely G30, G40, G50, G60 and G70, were developed with varying GGBS contents (30–70% replacement of OPC), including a control mix without GGBS (G0). Three (3) additional mixes (P5, P10 and P15) were prepared with PP fibre volumes of 0.5%, 1.0%, and 1.5%. All mixes consisted of 20% EPA and 80% SS, maintaining a sand to cement ratio of 2.5 and a water to binder ratio of 0.5. The specimens were cured for 28 and 56 days, then exposed to elevated temperatures of 200°C, 400°C, 700°C, and 1000°C to evaluate their residual performance. The results revealed that the inclusion of GGBS improved the flowability and reduced the mass loss of CI, while the incorporation of PP fibres reduced workability and increased mass loss. Among all specimens, G30 (30% GGBS replacement) and P5 (0.5% PP inclusion) demonstrated the highest RCS, RFS, and RTS after exposure to 1000°C for both curing ages, while G50 and P10 exhibited superior residual rebound hammer (RRH) and residual UPV (RUPV) values. The combination of GGBS and PP fibres was found to significantly influence the thermal conductivity, decomposition behaviour, and microstructural stability of CI as evidenced by TC, TG, DSC, and SEM analyses. Subsequently, 25 mm thick layers of G30 and P5 CI were applied to full-scale RC columns (200 mm × 200 mm × 2640 mm) and tested under fire exposure. The findings confirmed that both G30 and P5 substantially enhanced the fire endurance of RC columns compared to the uninsulated control specimen. Furthermore, two (2) finite element models (FEM) were developed and validated using existing literature and experimental data, effectively simulating the temperature evolution and thermal performance of the P5 insulation system. In summary, this research establishes that GGBS and PP based CCs can be effectively utilized as sustainable and high-performance CI for improving the fire resistance of RC structures.

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CHAPTER 1
INTRODUCTION

1.1 Research Background

Improving, upgrading or strengthening concrete structures may be required for many reasons. The concrete has become structurally inadequate due to deterioration of materials, poor initial design, lack of maintenance, inappropriate construction technique, upgrading of design load, damaged caused by fire and other catastrophic events. There are various techniques of improving, upgrading or strengthening concrete structures for instance using steel plate (Ciampa et al., 2022, 2023; Khaloo et al., 2024; Li et al., 2023; Liang et al., 2011; Lim et al., 2025; Liu et al., 2020, 2023; Shen et al., 2005; Wang et al., 2015; Wang, S.C et al., 2020; Wei et al., 2024; Ying et al., 2017).

Currently, Fibre Reinforced Polymer (FRP) is an alternative for reinforced concrete (RC) structures restoration instead of demolishing and rebuilding the new RC structures which is not always economic. There are two (2) types of FRP commonly used which are Glass Fibre Reinforced Polymer (GFRP) and Carbon Fibre Reinforced Polymer (CFRP) (Frhaan et al., 2021; Huang et al., 2007; Kim et al., 2010; Kinjawadekar et al., 2024; Li et al., 2007, Li et al., 2012; Luo et al., 2025; Medhlom & Abed, 2023; Thang et al., 2021; Zhou, Z et al., 2023). FRP consists of carbon or glass fibres embedded in a polymer resin matrix. The fibres primarily provide high strength and stiffness, while the resin or polymer acts as a binding medium that transfers stresses between fibres, protects from environmental exposure, and enhances the overall durability of the composite. In recent years, CFRP has gained significant attention for reinforcing existing bridges and buildings, including beams, columns, slabs, and foundations, in structural rehabilitation works. The advantages of using CFRP such as high durability, high elastic modulus and high resistance to environmental degradation factors enhanced the performance of the structure when the former is used for strengthening (Blikharskyy et al., 2018; Hackett, 2005; Hu et al., 2013; Jahami & Issa, 2024; Kim et al., 2010; Li, 2022; Myers & Muncy, 2014; Rusinowski et al., 2006; Sena-Cruz et al., 2015; Seniwongse, 2008; Sikora & Ostrowski, 2025; Solahuddin & Yahaya, 2023; Vorwagner & Burtscher, 2010). Moreover, using CFRP as strengthening material associates with minimum hacking, patching, and it also lightweight and anti-corrosive