# UNIVERSITI TEKNOLOGI MARA

# SYNERGISTIC EFFECT OF GRAPHENE OXIDE (GO) AND ADDITIONAL WATER CONTENT ON MICROSTRUCTURE, DURABILITY, AND BOND STRENGTH PROPERTIES OF GEOPOLYMER MORTAR

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# ABSTRACT

Geopolymer mortars (GPM) are currently being explored as sustainable material alternatives to ordinary Portland cement-based mortars. However, GPM mix performance depends on the precursor, the alkaline-activated solution, the water content, and any additional materials. Graphene oxide (GO) is a promising nanomaterial with 3 major behaviors: it can act as a filler, a bridge, and a binder. However, the effectiveness of GO is highly dependent on its dosage and the availability of sufficient water for proper dispersion, as GO's hydrophilic nature tends to absorb water, reducing workability and altering the geopolymerization process, potentially leading to high porosity and weaker bond strength. The chemical composition, elements, and microstructure of the material influence both fresh and hardened properties of GPM. Hence, this study analyzed the physical and chemical characteristics of the raw materials, namely, fly ash class F (FA), ground granulated blast furnace slag (GGBS), and GO. The GPM formulation, incorporating different GGBS replacement levels in FA (0%, 20%, 40%, 60%, 80%, and 100%) and without GO, was investigated for flowability, compressive strength, setting time, and dry shrinkage. An optimum GPM formulation was chosen as the baseline mix based on its overall performance across the tested properties. Six different GO dosages (0 wt.%, 0.02 wt.%, 0.04 wt.%, 0.06 wt.%, 0.08 wt.% and 0.10 wt.%) with 3 different water-to-precursor ratio (w/p) (0.00, 0.10, and 0.20) were included in the baseline mix (GO0-GPM) to investigate its performance on flowability, setting time, compressive strength, dry shrinkage, water absorption, acid attack, and rapid chloride permeability. A total of 18 mix designs were analyzed in this phase, and 6 were selected as desired based on their combined fresh, hardened, and durability performance. The pore characteristics of the desired mixes were analysed, as was the bond behaviour. Bi-surface shear bond strength, slant shear bond strength, splitting tensile bond strength, and interfacial bond morphology (IBM) were analysed. Mohr's Coulomb Principle was used to analyze the stress on the bond interface. The results showed that the performance of GPM was not controlled by GO dosage alone, but by the interaction between GO content and w/p ratio. The results further confirmed that incorporating 0.04-0.06 wt.% GO with w/p 0.10 enhanced the bonding performance of GPM by promoting a denser interfacial microstructure and improving shear resistance across the interface. Among the investigated mixes, the optimum range of 0.04-0.06 wt.% GO with w/p 0.10 produced the most balanced performance by improving matrix densification, pore refinement, durability resistance, and interfacial bond behaviour. The observation on microstructural characteristics aligns with the observed mechanical improvements and indicates that GO functions as a nano-reinforcement and nucleation agent, thereby promoting more efficient geopolymerisation. The synergistic effect of GO and water was analysed on fresh, hardened, and bond behaviour properties, and the findings provide a practical basis for optimising low-dosage GO-modified GPM where bond strength and durability are critical.

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# CHAPTER 1
# INTRODUCTION

## 1.1 Introduction

Geopolymer was first introduced by Joseph Davidovits in the 1970s (Davidovits, 2017) representing a major turning point in the development of low-carbon construction materials. Geopolymer mortar (GPM) is an alternative to the conventional Portland cement (OPC) mortar that used industrial by-product which are rich in alumina and silica, such class F fly ash (FA) (Mohana & Leela Bharathi, 2022), ground granulated blast furnace slag (GGBS) (Kuri et al., 2022), metakaolin (MK) (Alanazi et al., 2016; Shalini et al., 2016), and rice husk ash (RHA) (Saloni et al., 2021) as the precursors. The combination of an aluminosilicate precursor and an alkaline activator, commonly comprising sodium hydroxide (NaOH) and sodium silicate ($Na_2SiO_3$), produced a geopolymer binder. The alkaline activation of aluminosilicate materials involves polymerisation events that yield an amorphous or semi-crystalline structure known as geopolymer (Ahmed et al., 2025).

Compared to OPC, geopolymer materials offer the benefits of fast setting times, greater early strength, and comparatively reduced costs. Depending on the precursors, most geopolymers attain over 60% of their ultimate strength within only three days of curing (Yan et al., 2025). However, despite the strength performance, GPM faces some challenges that limit its application in construction (Yang et al., 2024). The efficiency of GPM is significantly affected by the properties of the precursor materials. Changes in chemical composition, elemental constituents, and morphology can profoundly influence reaction kinetics, microstructural development, and mechanical properties of the hardened matrix (Rodrigue Kaze et al., 2021). Consequently, a clear understanding of the precursor's chemical and physical characteristics is essential to maintaining consistent material quality and optimising overall performance. In addition, GPM with high solid content was reported reduced workability and exhibited high dry shrinkage when exposed to ambient conditions (Hassani & Kazemian, 2024; Park & Pour-Ghaz, 2018). Furthermore, the pore characteristics of GPM vary widely and inconsistently due to incomplete precursor dissolution, resulting in residual voids, hence, deteriorate the durability performance over time (Duan et al., 2016; Khan et al., 2020). The porous