UNIVERSITI TEKNOLOGI MARA

PERFORMANCE OF CONTROLLED LOW-STRENGTH MATERIAL CONTAINING FLY ASH AND WASTE PAPER SLUDGE ASH AS GROUND BACKFILLING MATERIAL

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ABSTRACT

Amidst mounting pressure on the cement and concrete industries to adopt environmentally sustainable practices, addressing the sustainability challenges associated with ground backfilling, particularly employing controlled low-strength materials (CLSM), becomes imperative. Despite the promising potential of integrating industrial by-product wastes such as fly ash (FA) and waste paper sludge ash (WPSA) as supplementary cementitious materials (SCM) in CLSM, a significant gap persists in the availability of comprehensive guidelines for formulating mixtures with these non-conventional materials, hindering widespread adoption. To tackle this challenge, this research leverages statistical experimental design techniques to optimise CLSM formulations using solely industrial by-product waste resources systematically. Investigating the properties and environmental impact performances of these optimised mixtures, the study employed a response surface method to examine the influence of key parameters on CLSM properties. Four (4) phases were undertaken: mix design, analysis of key parameters, optimisation and validation, and evaluation of optimised CLSM backfill. Statistical models were developed in the mix design phase to evaluate fresh and hardened properties considering three (3) key parameters: water-cementitious material (w/cm) ratio, SCM percentage (ranging from 50% to 100% of total cementitious materials), and total cementitious materials content. Subsequent analysis revealed the impact of these parameters on properties such as flowability, bleeding, segregation, initial stiffening time, and densities (fresh, air-dried, oven-dried), among others. Optimised statistical models identified an optimal w/cm ratio of 2.53 for balanced flowability and segregation resistance, while a total cementitious materials content of 200 kg/m^3 enhanced segregation resistance and fluidity. Increased FA% and WPSA% levels notably improved flowability, with FA-CLSM showing enhanced flowability at higher FA percentages. Notably, FA-CLSM achieved an Unconfined Compressive Strength (UCS) of 3131.02 kPa at a 2.53 w/cm ratio, surpassing WPSA-CLSM mixtures. Environmental assessments revealed leachate concentrations of heavy metals well below regulatory limits, ensuring non-hazardous disposal of CLSM mixtures. Validated statistical models offer guidance for efficient mix design processes, underscoring the significance of tailored CLSM formulations for enhancing performance and sustainability in construction practices.

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CHAPTER 1
INTRODUCTION

1.1 Research Background

Backfilling is a crucial aspect of the construction industry, especially with the growing emphasis on sustainable infrastructure development. Controlled Low-Strength Material (CLSM), or flowable fill, gains prominence for its eco-friendly nature and versatility (Bouzalakos et al., 2013; Park et al., 2018). Research on granulated copper slag reveals its potential to enhance pozzolanic activity, offering innovative backfilling materials (Do et al., 2015; Feng et al., 2019). Additionally, the study on geosynthetics pullout in recycled construction material underscores the viability of eco-friendly alternatives (Frare et al., 2020). Investigation into defects in residential construction emphasises proper backfilling for stability, aligning with quality and sustainability goals (Sun et al., 2017; Tayeh et al., 2020).

The adoption of CLSM has been driven by its numerous advantages, such as low cost, rapid placement rate, and versatility in construction projects (ACI 229R-13, 2013; Bouzalakos et al., 2013). Additionally, CLSM has emerged as an economical backfill material capable of incorporating waste materials, further enhancing its appeal (Ibrahim et al., 2022; Lu et al., 2019; Meegoda et al., 2003). By incorporating locally sourced industrial waste materials, including slag, fly ash (FA), Waste Paper Sludge Ash (WPSA), red mud, kiln dust, fine recycled aggregate (FRA) and silty soil, CLSM offers a sustainable solution for backfilling and geomaterial stabilisation that is both profitable and environmentally sustainable (ACI 229R-13, 2013; Bouzalakos et al., 2013; Mahamaya, 2018; Mahamaya et al., 2023; Wang et al., 2022). Utilising these waste materials in CLSM can minimise the environmental impact of construction projects and reduce waste sent to landfills (Casanovas-Rubio et al., 2019; Dudeney et al., 2013; Wu et al., 2016). Furthermore, previous studies have demonstrated that incorporating binary cementitious materials with waste materials can enhance cement-based systems, extending these benefits to CLSM mixtures (Folliard et al., 2008; Gabr & Bowders, 2000; Neville, 2013; Sarhosis & Sheng, 2014). The inclusion of supplementary cementitious materials (SCMs) like FA and WPSA has been found to enhance the fresh, mechanical, and durability properties of CLSM, making it an