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Recycled asphalt pavement – fly ash geopolymers as a sustainable pavement base material: Strength and toxic leaching investigations

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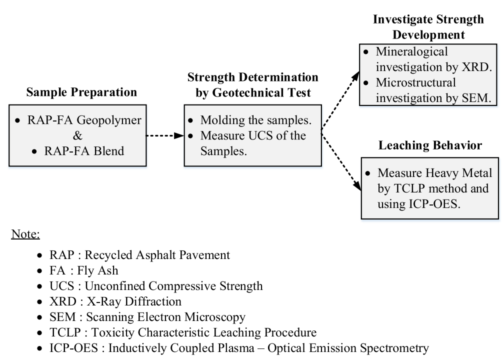
HIGHLIGHTS

- Environmental evaluation of fly ash (FA) based geopolymer stabilized Recycled Asphalt Pavement (RAP).
- Microstructural development was examined via XRD and SEM analyses.
- UCS of RAP-FA geopolymers and RAP-FA blends were compared with road authorities' requirements.
- The leachability of the heavy metals is measured by TCLP and compared with international standards.

GRAPHICAL ABSTRACT



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ABSTRACT

In this research, a low-carbon stabilization method was studied using Recycled Asphalt Pavement (RAP) and Fly Ash (FA) geopolymers as a sustainable pavement material. The liquid alkaline activator (L) is a mixture of sodium silicate (Na_2SiO_3) and sodium hydroxide (NaOH), and high calcium FA is used as a precursor to synthesize the FA-RAP geopolymers. Unconfined Compressive Strength (UCS) of RAP-FA blend and RAP-FA geopolymer are investigated and compared with the requirement of the national road authorities of Thailand. The leachability of the heavy metals is measured by Toxicity Characteristic Leaching Procedure (TCLP) and compared with international standards. The Scanning Electron Microscopy (SEM) analysis of RAP-FA blend indicates the Calcium Aluminate (Silicate) Hydrate (C-A-S-H) formation, which is due to a reaction between the high calcium in RAP and high silica and alumina in FA. The low geopolymerization products (N-A-S-H) of RAP-FA geopolymer at NaOH/Na_2SiO_3 = 100:0 are detected at the early 7 days of curing, hence its UCS is lower than that of RAP-FA blend. The 28-day UCS of RAP-FA geopolymers at various NaOH/Na_2SiO_3 ratios are significantly higher than that of the RAP-FA blend, which can be attributed to the development of geopolymerization reactions. With the input of Na_2SiO_3, the highly soluble silica from Na_2SiO_3 reacted with leached silica and alumina from FA and RAP and with free calcium from FA and RAP; hence the coexistence of N-A-S-H gel and C-A-S-H products. Therefore,

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the 7-day UCS values of RAP-FA geopolymers increase with decreasing $NaOH/Na_2SiO_3$ ratio. TCLP results demonstrated that there is no environmental risk for both RAP-FA blends and RAP-FA geopolymers in road construction. The geopolymer binder reduces the leaching of heavy metal in RAP-FA mixture. The outcomes from this research will promote the move toward increased applications of recycled materials in a sustainable manner in road construction.

1. Introduction

Highway construction is an important aspect in infrastructure construction in many developed and developing countries. Highway construction however consumes a large amount of natural quality aggregates, particularly in their pavement base/subbase layers. As a result, the quarries and gravel pits are increasingly exploited as a source of pavement materials, which notably leads to subsequent devastating of natural environmental resources. The urgent need for new environmentally friendly solutions have made researchers explore new alternative materials that will reduce energy consumption, and greenhouse gas emissions. Sustainable strategies increasingly pursued to date, have resulted in the application of novel economical techniques which have less environmental impact and which will lead to more efficient use of natural resources (Moreno et al., 2012). An important environmental strategy increasingly sought by the road construction industry is the use of recycled materials in pavement base/subbase layers.

Several researchers have in recent years investigated the usage of recycled waste materials as substitutes for virgin materials in the civil infrastructure applications, such as in pavements, footpaths and embankments. Materials such as recycled glass (Disfani et al., 2012; Grubb et al., 2006; Wartman et al., 2004), melamine debris (Donrak et al., 2016), recycled concrete aggregate (Poon and Chan, 2006; Tam, 2009), recycled asphalt pavement (RAP) (Arulrajah et al., 2013; Puppala et al., 2011; Suebsuk et al., 2014; Taha et al., 2002), and various other forms of recycled construction and demolition (C&D) materials (Arulrajah et al., 2012) have been recently evaluated for embankment, pavement, footpath, and pipe-bedding applications (Rahman et al., 2014). Calcium carbide residue is a by-product of the acetylene production process and has been established as a binder for soil stabilization (Horpibulsuk and Kampala, 2012; Horpibulsuk et al., 2011; Kampala et al., 2013; Phetchuay et al., 2016 and Phummiphan et al., 2016). Water treatment sludge and fly ash have been used to manufacture sustainable geopolymer masonry units (Horpibulsuk et al., 2015; Suksiripattanapong et al., 2015b; Suksiripattanapong et al., 2015a and Nimwinya et al., 2016).

Recently, Hoy et al. (2016) reported on the novel low-carbon geochemical stabilization of RAP for pavement base/subbase applications, namely with a Recycled Asphalt Pavement – Fly Ash blend (RAP-FA blend) and a Recycled Asphalt Pavement – Fly Ash geopolymer (RAP-FA geopolymer). A large amount of RAP, of up to 80% could be used as a coarse aggregate. A liquid alkaline activator (L), a mixture of sodium hydroxide solution (NaOH) and sodium silicate solution (Na_2SiO_3), was used to synthesis the RAP-FA geopolymer, while for the RAP-FA blend, a mixture of RAP, FA, and water was prepared as a control material to investigate the effect of L on strength development. Both the RAP-FA blend and RAP-FA geopolymer products were found to be viable in pavement base applications as their Unconfined Compression Strength (UCS) results were greater than the minimum strength requirement specified by the Department of Highway, Thailand.

Though the utilization of recycled waste materials in highway construction can be considered as having significant impacts on resource management, the hazardous compounds that can leach out and pollute the water resource should also be considered (Dawson, 2009). A range of heavy metals and other pollutants including oil and/or organic micro-contaminants may be present in the recycled material and should be ascertained for pavement base applications (Apul et al., 2002; Dawson et al., 2006; Hill, 2004; Olsson, 2005). Sherwood. (2001) studied the usage of alternative materials in road construction and indicated that contamination depends on the concentration of the toxic substance and the quantity of material being used. Sherwood. (2001) furthermore reported that water pollution could arise where embankments were constructed close to ground water sources and when drainage from the road embankments discharges directly into a watercourse, resulting in serious impacts on aquatic life. Similar works by Dawson (2009); Disfani et al. (2012), and Arulrajah et al. (2014 and 2015) on the flow water balance in road construction revealed that the infiltration and seepage from the road surface would occur in the road structure, which will lead to chemical reaction with materials in the various road layers and the underlying soil.

Literature (Gupta et al., 2009; Legret et al., 2005) showed that there was the potential leaching of contaminants resulting from RAP itself as well as the pulverization of the binder or additives used to stabilize RAP in road construction applications. The contamination is primarily related to pH, Polycyclic Aromatic Hydrocarbons (PAH), and a variety of metals. A dual channel pH conductivity meter was used to read the pH of free water by soaking 100% RAP and cement-treated RAP samples (Hoyos et al., 2008; Hoyos. et al., 2011). The neutral pH values of approximately 6 to 7 of 100% RAP were found while the pH of cement-treated RAP and cement-treated RAP with fiber tends to increase with an increase in cement dosage. Li et al. (2008) studied the utilization of RAP with 10% of class C fly ash for a road base construction and reported that leachate from this blend ranged from 6.9 to 7.5.

Kang et al. (2011) studied the leachate assessment of various recycled materials, including Reclaimed Concrete Aggregate (RCA), FA, and RAP. It was found that pH levels in RAP leachate were 7.57 and 9.67 for unsaturated leachate tests and batch tests, respectively. When FA was added in RAP + RCA, the pH values were 9.7 and 10.99 for the 5%FA + 25%RAP + 70%RCA and 15%FA + 75%RAP + 10%RCA. The authors concluded that when up to 5% of FA content was used, an insignificant substantial leaching of metals apart from aluminum took place. Moreover, the mixtures containing 15% FA resulted in considerable leaching of metals as the residence time increased.

Shedivy et al. (2012) performed laboratory batch leachate tests on RAP by using both Toxicity Characteristic Leaching Procedure (TCLP) fluid and deionized water. The results showed that the PAH levels included acenaphthalene, benzo(a)anthracene, benzo(b)fluoranthene, benzo(a)pyrene and benzo(ghi)perylene which were very close to the U.S. EPA drinking water standards. In addition, all metals except manganese and arsenic were below the Maximum Contamination Level (MCL) concentration for drinking water.

Though suitable mechanical properties of RAP-FA blend (Li et al., 2009; Mohammadinia et al., 2016; Wen et al., 2010) and RAP-FA geopolymer (Hoy et al., 2016) have been previously reported by several authors, the limited knowledge of the environmental risks of these materials remain as primary barriers to their reuse in pavement applications. Therefore, in this research, the most reliable leachate tests to estimate the contaminant concentration in the seepage water (Susset and Grathwohl, 2011), which provide information about the impacts on groundwater in the life cycle of the projects (Hellweg et al., 2005) were undertaken to cover the knowledge gap on possible environmental risks of using RAP-FA blend and RAP-FA geopolymer in road work application. The outcomes of this research will facilitate the move