

CHAPTER II

LITERATURE REVIEW

2.1 Introduction

The literature on the application of BA and RCA in geopolymer as a subbase layer and pavement base for road building is presented in this chapter. An overview of the specifications for pavement construction and the technical characteristics of Recycled concrete aggregate (RCA) and Bottom (BA) is given first. When RCA and BA are used in the pavement base and subbase application, their engineering qualities—such as gradation, strength, compacted density, moisture content, permeability, and durability—are very valuable.

This chapter also covers the structural characteristics of the mixes of virgin aggregates, BA and RCA, that are utilized as a road structure. Researchers have discovered alternative stabilized techniques for building heavy-load roads as a result of advancements in pavement design, which called for greater quality pavement base structure qualities. This chapter highlights one of the most often utilized methods and procedures: the chemical stabilization of Portland cement (PC) treated granular aggregates.

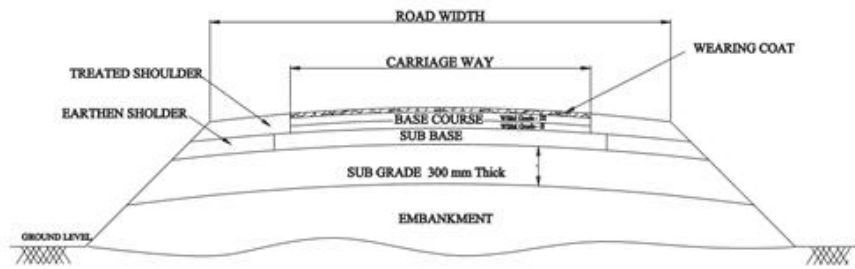
The trend to replace PC products with a low-carbon chemical stabilized method called geopolymer is then presented, as environmental issues are a major global concern. An overview of geopolymer chemistry uses fly ash applied to applications, and the use of bottom ash-based geopolymer is less than fly ash given in construction material. Included is a mechanical theorem for geopolymer-stabilized recyclable materials based on bottom ash. Furthermore, the broad ideas of the primary environmental issues are covered in this chapter. These issues are extremely important for highway design, development, rehabilitation, construction, and maintenance.

2.2 Specification for pavement construction

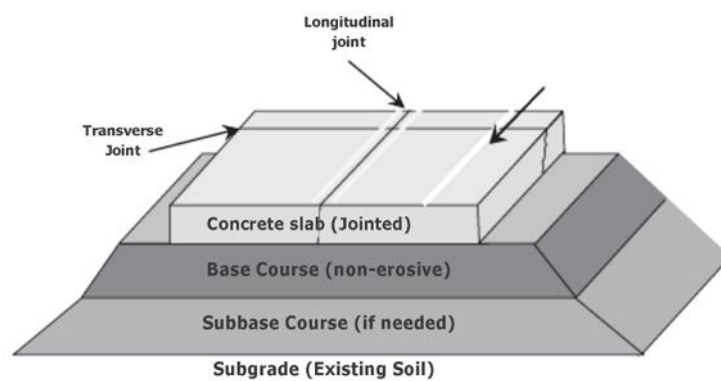
Typically, each nation has its own Department of Highways or Department of Rural Roads with full autonomy over highway matters. Nonetheless, Thailand's national road authorities have incorporated international standards, including those of the American Society of Testing Materials (ASTM) and the American Association of State Highway and Transportation Officials (AASHTO), into their specifications. Subbase and

base material requirements have been released by both international standards. For use in the construction of subbase, base, and surface courses, the specification takes on the quality and grading of the following materials sand-clay mixtures gravel stone or slag screenings sand crusher-run coarse aggregate which is made up of gravel, crushed stone, or slag mixed with soil mortar; or any combination of these materials. (Hoy, 2016)

Type of pavement in road construction, there are several different types of pavement used for the construction of roads, highways, airport runways, parking lots, and other paved surfaces. The main types of pavement include flexible pavements Figure 2.1 (a), rigid pavements or semi-rigid pavements Figure 2.1 (b), composite pavements, and interlocking cement concrete block pavement. The choice of pavement type depends on factors such as anticipated traffic loads, environmental conditions, construction costs, and maintenance requirements. Asphalt concrete and jointed plain concrete pavements are the most widely used types for highways and roads. All hard-surfaced pavement types may be broadly divided into two groups stiff and flexible. Bituminous, or asphaltic, surfaces are used to surface flexible pavements. These can take the form of HMA surface courses, which are often utilized on larger volume roads like the Interstate highway network, or pavement surface treatments, such as bituminous surface treatments (BST), which are typically seen on lower volume roads. These pavements are referred to as flexible because the weight of the traffic causes the entire pavement structure to bend or deflect. The majority of the time, a flexible pavement construction is made up of many layers of materials that may bend or bend. Conversely, a PC surface course is made up of stiff pavements. Because PC has a high modulus of elasticity, these pavements are significantly "stiffer" than flexible pavements. Additionally, reinforcing steel, which is often utilized to minimize or eliminate joints, may be used in these pavements.



(a)

**Cross section of Rigid Pavement**

(b)

Figure 2.1 Typical pavement construction layers (a) flexible pavement, and (b) concrete pavement (rigid) (not to scale)

2.3 Recycled concrete aggregate (RCA) in construction

Recycling the concrete aggregates left over from specific building procedures can help preserve natural resources and lessen the amount of garbage dumped in nearby landfills (Khan, Wang, & Sarker, 2018). However, a lot of state and federal highway contracts mandate the use of recycled materials in the construction of new roads; the market determines the availability, engineering performance, and financial incentives that drive the rising rate of utilization. In order to build pavement subbases and bases that are more durable at a reasonable cost, it is now imperative to make use of the most recent advancements in alternative cementing methods and accessible RCA. A type of alternative binding material that is well-known is geopolymer binders based on fly ash. These materials belong to a class of low-carbon industrial

byproduct materials. Its application in unbound pavement base and subbase applications has attracted increasing attention in research in the last several years. After much research on this material, it is now well established that using geopolymer technology may significantly cut CO₂ emissions with no negative economic impact. (Gautreau, Zhang, & Wu, 2010; Nisbet, VanGeem, Gajda, & Marceau, 2000) A range of studies have explored the properties and characteristics of recycled concrete aggregate. (Ryu, 2002) found that the aggregate significantly impacts the interfacial property, permeability, and strength of concrete. (Sagoe, Brown, & Taylor, 2002) reported that the differences between fresh and hardened properties of recycled aggregate concrete and natural aggregate concrete are relatively narrow, with some variations in abrasion loss and drying shrinkage. (J.-h. Kim, Sung, Jeon, Lee, & Kim, 2019) focused on the mechanical and durability characteristics of concrete using recycled aggregate, noting improvements in various properties. (Rakshvir & Barai, 2006) highlighted the need to compensate for the greater water absorption of recycled aggregates during mix design and observed a decrease in compressive strength with increasing percentages of recycled concrete aggregates.

The use of recycled concrete aggregates (RCA) in road construction has been extensively studied, with promising results. (Puthussery, Kumar, & Garg, 2017) found that the physical and mechanical properties of RCA were suitable for road construction, with only a slight decrease in tensile strength. (Contrafatto, Cosenza, Barbagallo, & Ognibene, 2018) further supported this, demonstrating that RCA can be used in road sub-base construction and concrete manufacturing, with a higher percentage of recycled aggregates being effective in concrete preparation. However, (Jayakody, Gallage, & Kumar, 2014) noted that the properties of RCA can be inconsistent, with some samples not meeting the minimum requirements for base materials in road construction. (Rakshvir & Barai, 2006) also highlighted the need to compensate for the greater water absorption of recycled aggregates during mix design. These studies collectively suggest that while RCA can be a viable option for road construction, careful consideration of its properties and appropriate mix design are crucial.

The concrete industry has recently become more aware of geopolymers, and several studies have been carried out to examine both their immediate and long-term performance (Concrete, 2005; Davidovits & Sawyer, 1985; Hambling, 2009; Han, Pyzik, & Liu, 2014; Rangan, 2008). According to a 2013 survey, the road base is used for around 68% of recycled concrete aggregate (RCA), with the remaining RCA going toward fresh concrete mixes, asphalt hot mixes, high-value riprap, and low-value items like general fill. (Odion, Khattak, Abader, & Heim, 2019). However, 27% of fly ash is employed in

loose form in structural fills and embankments, and around 50% of fly ash is used in bound form in concrete products (Kravchenko & Ruhl, 2021). Furthermore, a number of research have been published on the use of geopolymers based on alkali-activated fly ash to enhance the mechanical properties of soils. These investigations have demonstrated that the flash content is essential to the geopolymerization process and that the soil mixes' unconfined compressive strength (UCS) rose as the fly ash level increased, peaking at 30% (Cristelo, Glendinning, Miranda, Oliveira, & Silva, 2012; Phummiphan et al., 2018; Zumrawi & Mohammed, 2016).

2.4 The highway construction

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 the 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 (Hoy, Horpibulsuk, Rachan, Chinkulkijniwat, & Arulrajah, 2016). Highway pavement generally consists of base, subbase, and engineering fill layers, which are typically constructed from suitable materials such as crushed rock and lateritic soil. The government of Thailand's current priority is in the economic expansion of the country over the next decade and has allocated a large budget for the construction of roadway networks across the country.

A number of road infrastructure projects have been implemented to construct transportation systems, particularly in rural areas. Heavy rain during the rainy season frequently causes flooding problems in some regions of Thailand. Hence, road embankments in the country must have an adequate thickness and must also be constructed with durable pavement materials. In general, the subbase/base layer is typically 50–70 cm in thickness, to ensure the road profile is above the flood level. Road construction consumes a vast amount of high-quality materials. The transportation of high-quality imported materials from distant sources increases the road construction cost considerably. Furthermore, transportation of imported materials significantly increases road maintenance costs and the carbon footprint.

The utilization of local resources at the road construction site is thus beneficial from both economic and environmental aspects, which is an approach that is strongly encouraged by the Department of Rural Roads and the Department of Highways,

Thailand (Sukprasert et al., 2021). The scientific and practical methodologies and outcomes from previous research have been reviewed and summarized in this paper in order to make a new illuminating study on cleaner production as well as to assure that waste materials can be mixed with soil as an intuitive practitioner interface technique in pavement applications (Sudla et al., 2018). For each road construction materials, BA was used in highway embankment construction offers an attractive alternative to disposal because substantial economic savings can be attained by the reduction of ash disposal costs and the conservation of natural soils and lands, pavement construction (Gautam, Kalla, Jethoo, Agrawal, & Singh, 2018; López-López, Vega-Zamanillo, Calzada-Pérez, & Taborga-Sedano, 2015; Yoo, Park, & Vo, 2016) and aggregate replacement in concrete pavement production (Arenas, Marrero, Leiva, Solís-Guzmán, & Arenas, 2011; Hannan et al., 2020; Ibrahim, Hamzah, Jamaluddin, Ramadhansyah, & Fadzil, 2015).

As traffic volumes and vehicular axle weights continue to increase with the increasing world population, highway construction and maintenance work have become widespread in all parts of the world (Nwakaire, Yap, Onn, Yuen, & Ibrahim, 2020). As these road construction activities become more frequent, there is an increasing demand for construction materials. There is a global trend to improve sustainability, particularly in the construction industry, due to increased waste generation and consumption of natural materials. Using waste materials for pavement construction has become a viable alternative for preserving natural materials and solving waste disposal problems.

Recycled concrete aggregate (RCA) for example has been used as an alternative unbound material to partially replace crushed rock in pavement applications (Behiry, 2013; Hoy, Tran, et al., 2023; Suddeepong, Hoy, et al., 2022; Tran et al., 2022). The construction of pavements involves a series of layered components such as a subbase, base, and surface course, each with a specific role. The sub-base, which sits directly atop the prepared natural ground level or subgrade, is usually composed of locally sourced materials or stabilized soil. It is designed to evenly distribute the load from the base to the subgrade, effectively safeguarding the impact of aggressive moisture. The base layer above the subbase often consists of crushed aggregate designed to further distribute the load, thereby providing a stable surface for the subsequent pavement layer and protecting the underlying subbase from detrimental environmental effects. The surface course is constructed using high-quality materials like asphalt or concrete, ensuring its ability to resist traffic loads and provide a durable and skid-resistant surface, making it critical for safety and efficiency in transportation.

Based on the type of surface course, the pavement can be classified into flexible pavement (asphalt surface layer) and rigid pavement (concrete surface layer). Because of the rigidity behavior, the load in rigid pavements is distributed over a wide area of the subgrade. This reduces the stress on the subgrade and makes the pavement more tolerant to weaker or less uniformly compacted subgrades when compared with flexible pavement. In addition, rigid pavements are resistant to rutting and weathering and require less maintenance over time (Hrapović, 2023; Nosov, Ushakov, Fotiadi, & Stepush, 2020; Peng, 2022)

2.5 Recycled and reclaimed material in highway construction

There is increasing global interest in green materials for use in green buildings and the use of recycled materials in the construction and rehabilitation in the infrastructure sectors (Hoy, Horpibulsuk, & Arulrajah, 2016). In recent years construction projects have used recycled and reclaimed materials to save costs and focus on global warming. Several researchers have in recent years investigated the usage of recycled waste materials as substitutes for virgin materials in civil infrastructure applications, such as in pavements, footpaths, and embankments. Recycling of concrete aggregates resulting from certain construction processes offers a way to reduce waste disposal loads sent to area landfills and to extend the life of natural resources (Odion et al., 2019). The reuse of these recycled materials in civil engineering infrastructure applications will result in a low-carbon solution, considering that recycled materials have significant carbon savings, compared with virgin quarried materials. C&D materials are increasingly being used in pavement applications, particularly as a base/subbase material. C&D materials that have been evaluated and successfully implemented in recent years in roads, footpaths, and pipe-bedding applications include recycled concrete aggregate (Azam & Cameron, 2013; Poon & Chan, 2006). In many years researchers have been interested in reused of construction materials in applications include recycle concrete aggregate, and Reclaim Asphalt Pavement (Arulrajah, Piratheepan, & Disfani, 2014; Hoyos, Puppala, & Ordonez, 2011; Puppala, Hoyos, & Potturi, 2011; Taha, Al-Harthy, Al-Shamsi, & Al-Zubeidi, 2002) waste rock (Akbulut & Güreş, 2007; Arulrajah, Piratheepan, Ali, & Bo, 2012) and waste glass (Arulrajah, Ali, Disfani, Piratheepan, & Bo, 2013; Disfani, Arulrajah, Bo, & Hankour, 2011; Grubb, Gallagher, Wartman, Liu, & Carnivale III, 2006; Wartman, Grubb, & Nasim, 2004). Waste is generally considered to have no lasting value. A large quantity of municipality solid waste is generated by industrial, human and commercial activities. Recycling is a method of converting various wastes into useful materials that can be reused. Without

a proper recycling process, these wastes are undesirable materials that are disposed of in landfills, which can result in numerous environmental problems. For instance, some waste contains metal or toxic compounds that can contaminate the soil, surface, and groundwater (Sudla et al., 2018).

2.6 Geopolymer stabilization material for highway construction

Soil stabilization has shown to be economical as it provides cheap materials for the construction of low-cost roads. Portland cement stabilization is one of such methods, which has proven to be effective especially in the case of sandy soil due to the ease of pulverization. The primary reaction of cement is with the water in the soil, which leads to the formation of a cementitious material. Cement stabilized road bases using soil as a constituent, provide substantial support to the overlaying pavement layer thereby reducing stresses on subgrade soil. Thus, the use of soil-cement becomes cost-effective in areas that are deficient in aggregate resources. However, the high carbon footprint and cost of using cement for pavement base/subbase stabilization has led to seeking alternative low-carbon stabilization technique like flyash-based geopolymer. Further, the soil-cement causes shrinkage cracks in the base layer, which appear as reflective cracks in hot mixed asphalt (HMA) that are responsible for low ride quality and moisture damage in pavements (Odion et al., 2019). Although, many federal and state highway contracts specify the use of recycled materials in highway construction with increasing rate of usage being influenced by the availability, engineering performance, and financial incentives as determined by the marketplace. Hence, it has become essential to utilize the advanced alternate cementing technologies and available RCA to economically produce more durable pavement subbase and bases. One such alternate binding material is known to be fly ash-based geopolymer binders. These are class of materials resulting from industrial by-products with a low carbon footprint. Its use in unbound pavement base/subbase applications has generated growing research interest in recent years. This material has been investigated and it is now widely known that the utilization of geopolymer technology could substantially reduce CO₂ with minimum economic detriments (Gautreau et al., 2010; Nisbet et al., 2000).

Bottom ash was ground to a similar particle size as fly ash. Table 2.1 shows the significant chemical composition of coal ash using X-ray fluorescence (XRF). XRD patterns of fly ash and bottom ash displayed in Figure 2.2 show that fly ash contained a higher content of amorphous phase particles compared to the bottom ash. The crystalline phases are predominantly quartz and mullite.

Table 2.1 Chemical composition and physical properties of coal ash. (Chindaprasirt, Jaturapitakkul, Chalee, & Rattanasak, 2009)

Composition (%)	Fly ash	Bottom ash
SiO ₂	38.7	38.8
Al ₂ O ₃	20.8	21.3
FeO ₃	15.3	12.1
CaO	16.6	16.5
Na ₂ O	1.3	1.0
TiO ₂	0.5	0.8
MgO	1.3	1.7
K ₂ O	2.1	2.5
SO ₃	2.6	2.4
LOI	0.8	2.9
Retained on sieve no.325 (% by weight)	32	29

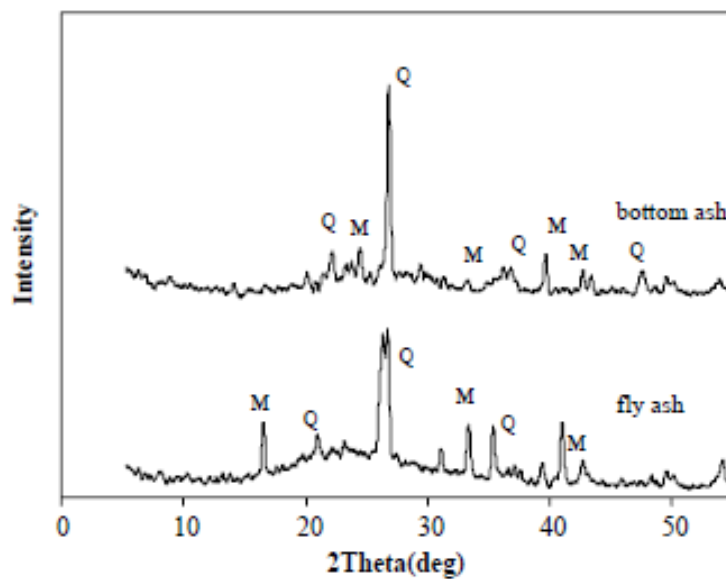


Figure 2.2 XRD patterns of fly ash and bottom ash. Q = quartz, M = mullite. (Chindaprasirt et al., 2009)

Recently, geopolymers have gained prominence attention in the concrete industry, building material, and road construction in pavement base/subbase layer, and several research studies have been conducted to address their short and long-

term performances. Geopolymer is made of alkali-activated aluminosilicate materials such as FA, slag, rice husk ash, and bottom ash. Geopolymers are reported to produce low CO₂ emissions and energy consumption (Palomo, Grutzeck, & Blanco, 1999). These shortcomings have led to an attempt to explore novel low-carbon stabilization methods. Geopolymer is an inorganic aluminosilicate material synthesized by alkaline activation of materials rich in alumina (Al₂O₃) and silica (SiO₂) and is considered a green cementing agent. Geopolymerization involves the chemical reaction of aluminosilicate oxides by alkaline activation, yielding the polycondensation of the material in the three-dimensional silico-aluminate structure (Davidovits, 1991; Zhang, He, & Gambrell, 2010). Three typical structures of geopolymer are: Poly (sialate) type (-SiO-Al-O-), the Poly (sialatesiloxo) type (-Si-O-Al-O-Si-O-) and the Poly (sialate-disiloxo) type (-Si-O-Al-O-Si-O-Si-O-). Geopolymer has in recent years been used to stabilize natural soils to develop green building materials such as masonry products. It was reported that geopolymer based materials possess higher compressive strength and durability against sulfate than cement-based materials (P. Sukmak, De Silva, Horpibulsuk, & Chindaprasirt, 2015; P. Sukmak, Horpibulsuk, & Shen, 2013; P. Sukmak, Horpibulsuk, Shen, Chindaprasirt, & Suksiripattanapong, 2013). Recently, (Suksiripattanapong, Horpibulsuk, Chanprasert, Sukmak, & Arulrajah, 2015) and (Horpibulsuk, Suksiripattanapong, Samingthong, Rachan, & Arulrajah, 2016) successfully stabilized water treatment sludge using fly ash based geopolymer to develop sustainable non-structural and bearing masonry units. It was illustrated that the geopolymer is more effective than PC in stabilizing the water treatment sludge with high alum content. The strength and durability of sludge-geopolymer masonry units are significantly higher than sludge-cement masonry units.

The compressive strength of geopolymer mortars after 48 hours of heat curing at 65°C. When compared to the bottom ash geo polymer, the fly ash geo polymer mortar offers a greater compressive strength. The outcomes also show that geopolymer mortars with relatively low strengths are produced by using a low NaOH concentration of 5 M. Using 5 M NaOH results in a mortar with a moderate strength of 24 MPa for the fly ash geopolymer. Using 10 M and 15 M NaOH results in higher strengths of 35 and 33 MPa. The compressive strengths of mortars for bottom ash are less than those of the fly ash geopolymer, 10, 14, and 18 MPa are the strengths of 5, 10, and 15 M geopolymer mortars, respectively. The thermograph suggests that the degree of polymerization of the bottom ash geo polymer is lower than that of the fly ash polymer. Compared to fly ash, bottom ash would have a lesser dissolution in the NaOH solution. Therefore, a larger concentration of NaOH is needed for the dissolution

of aluminum and silicon dioxide in bentonite ash, additionally. For the production of geopolymers, fly ash, and ground bottom ash are suitable sources. The findings of the compressive strength of geopolymer mortars shown in Figure 2.3 that fly ash exhibits a greater degree of geopolymerization and is more reactive than bottom ash. At 35 MPa, the compressive strength of the fly ash geopolymer mortar is remarkably strong and significantly greater than that of the bottom ash geopolymer mortar, which is only 18 MPa. The NaOH concentration affects a geopolymer's strength as well. For both types of ash, a 10 M NaOH concentration is the ideal one.

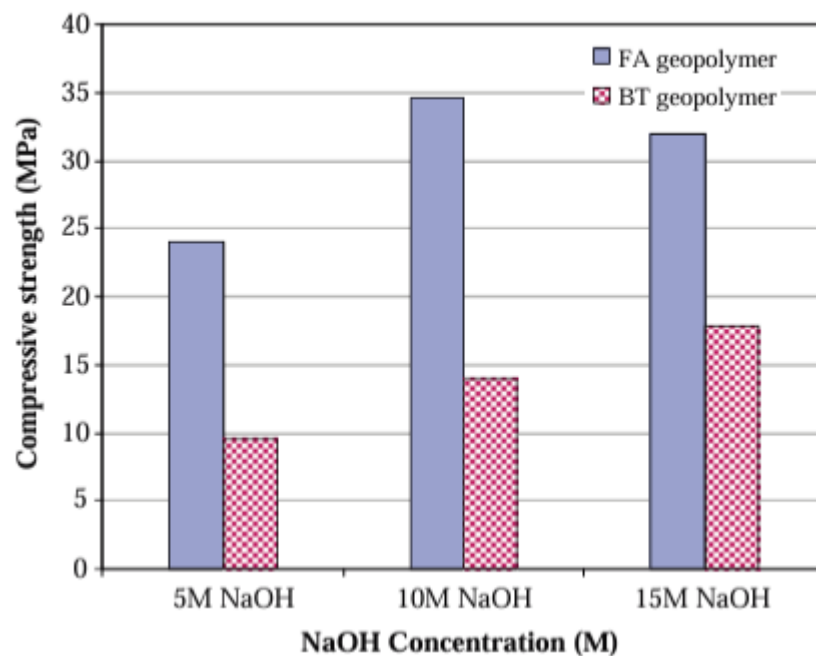


Figure 2.3 Compressive strength of geopolymer mortars between FA and BA
(Chindaprasirt et al., 2009)

2.7 Recycle concrete aggregate (RCA)

Globally, it is predicted that 2.59 billion tons of solid garbage would be produced yearly by 2030. This number is anticipated to increase even higher to 3.40 billion tons by 2050. According to estimates from the World Bank, only around 19% of solid waste was recycled or composted worldwide. (Cycling; Kaza, Yao, Bhada-Tata, & Van Woerden, 2018) (Odion et al., 2019) Researching the recycling of concrete aggregates, especially for use in road building, has become a feasible endeavor. The purpose of this study was to determine if recycled concrete aggregate (RCA) combined

with soil, fly ash, and alkali activator may be a viable substitute for soil-cement in applications involving road base or subbase. The final product, called Soil-RCA geopolymer, was created by combining different amounts of fly ash, RCA, sodium hydroxide, and silicate. Using a two-flyash experiment design, the impact of mixing factors on the mechanical characteristics of Soil-RCA geopolymer was examined. For the purpose of sensitivity analysis and ultimate mixture selection, models were also developed to estimate the unconfined compressive strengths depending on mixture characteristics. Based on the investigation and findings, the Soil-RCA geopolymer combination demonstrated good stiffness, strength, and durability. (Al-Mosawe, Albayati, Wang, & Mashaan, 2022) enhanced the characteristics of the pavement roadbed materials by using recycled concrete. The following findings were drawn from the experimental research and modeling for this project. RCA may be utilized in lieu of regular gravel materials at full size to satisfy the material specification requirements for building the pavement subbase layer. Compared to regular gravel, RCA materials have a greater optimal moisture content. The constant proportions for the coarse, fine, and ultrafine materials would be 0.026%, 0.471%, and 0.373%, respectively, if linearity is assumed. The overall bearing capacity and rigidity of the pavement structure will generally be improved when RCA is used in place of regular gravel material for subbase course construction. This effect will be more noticeable when asphalt is used for the pavement top layer. RCA replacement at a 75% coarse replacement, 50% fine replacement, or 100% extra fine replacement was the best usage of replacement to get a higher CBR value. When employing the CC RCA type, the critical tensile strain and maximum compressive strain were reduced by the 100% REF substitution. However, while utilizing the TTB RCA type, the 100% RFA substitution improved these two characteristics. Additionally, the robust modulus's value was optimized by these two suggested substitutions. The pavement structure's design life would be extended if the suggested replacement were to be used, as this would raise the number of permitted load repetitions.

2.8 Bottom ash (BA)

Every year, there is an increase in the consumption of fossil fuels to produce energy. Coal is mainly used to generate steam for industrial operation and electricity generation. Consequently, coal ash is obtained as a waste product that needs to be disposed in an environmentally friendly way. However, because of the large quantity produced, most types of ash, including fly and bottom ash, are disposed of in landfills. This disposal process leads to environmental and other problems (Chindaprasirt et al.,

2009). In Thailand, the annual output of fly ash and bottom ash from large and small power plants totals about 4.0 million tons. Approximately 1.8 million tons of fly ash is used as a pozzolanic material in the concrete industry. Over a million tons of black carbon are produced annually by Thailand's coal-fired power plants during their combustion process. An annual budget of USD 180,000 is allotted by the Electricity Generating Authority of Thailand (EGAT) to dispose of its BA waste in the waste disposal site. In order to assist the government of Thailand's national development program, EGAT looks for the best way to optimize the use of BA in road building. According to its characteristics, BA is a porous aggregate with a rough particle form, low bulk density, and high water absorption. In terms of geotechnical qualities, BA's hydraulic conductivity, shear strength, chemical soundness, and California Bearing Ratio (CBR) are on par with or superior to those of natural aggregates. For this reason, BA is typically employed as a stand-in. (Buritatum et al., 2022b)

The partial replacement of Portland cement with fly ash reduces the heat of hydration and improves the workability and durability of the concrete. However, the level of fly ash replacement is normally restricted to less than 40% of Portland cement (Mehta, 1998). Bottom ash (BA), in contrast, does not possess the same enhanced workability. However, the chemical constituents of these two materials are very similar, with the main difference being particle shape and size. Bottom ash is larger in size and very irregular, containing pores and cavities. Ground to a proper fineness, bottom ash can be used as a pozzolan that produces relatively high-strength concrete (Jaturapitakkul & Cheerarot, 2003). Both bottom ash and fly ash are by-products of the combustion of pulverized coal in power plants. As the temperature in the kiln is higher than the melting point of fly ash, the fly ash melts and forms the bottom ash. Bottom ash generally has a high porous surface and a large particle size, thus resulting in a higher water requirement and lower compressive strength when used in conventional cement concrete. The bottom ash could be grounded to reduce its particle size, thus decreasing the porosity and enhancing the pozzolanic reaction.

The SEM images of BA revealed that the particles were irregular with the agglomeration of spherical particles and some angular and rough particles as shown in Figure 2.4

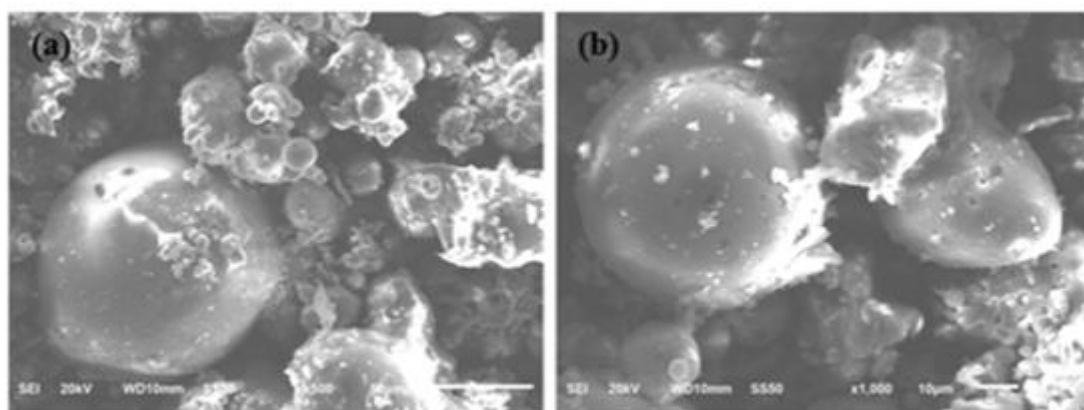


Figure 2.4 SEM image of BA at (a) 500x magnification (b) 1000x magnification.
(Kerarat, Kroehong, Thaipum, & Chindaprasirt, 2022)

However, the utilization of bottom ash as a cementitious replacement material has not yet been well received due to the need for grinding and the possibility of only the partial replacement of cement. But still, different studies done in this field have laid a foundation for the future utilization of bottom ash in the field of geopolymer paste and concrete production. The utilization would be a big positive step forward rather than treating the bottom ash as waste material (Sathonsaowaphak, Chindaprasirt, & Pimraksa, 2009). Bottom ash (BA) waste from Mae Moh Electric power plant in the north of Thailand is shown in Figure 2.6 The basic properties and particle-size distribution of BA are summarized in Table 2.1 and Figure 2.5, respectively. The particle-size distribution and soundness of BA did not meet the standard to be used as fine aggregate in asphaltwearing course, in accordance with the Thailand Department of Highways standard.

Table 2.2 Basic engineering properties of Bottom ash. (Buritatum et al., 2022a)

Properties	Bottom ash	DH-S 408/1989 Specifications
Soundness (%)	24.3	≤9%
Sand equivalent (%)	53.1	≥50%
Specific gravity	2.53	-

BA contained a high content of fine particles; particles smaller than 4.75 mm are greater than 50%. It is noted that BA particles were coagulated into clusters,

indicating that they react with water. In other words, BA is characterized as a hydrophobic material.

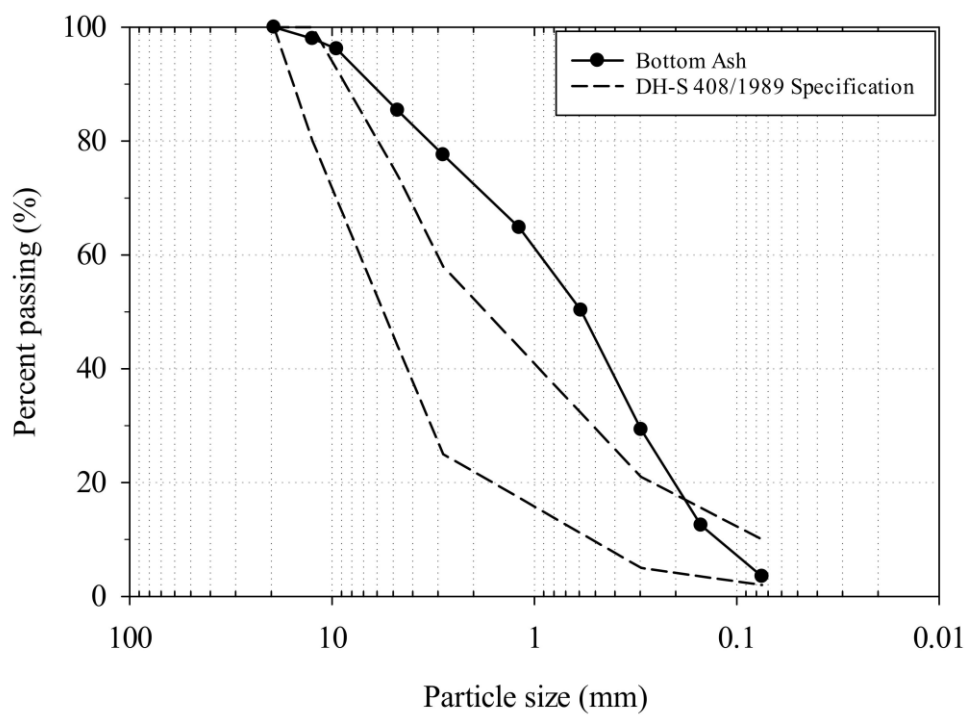


Figure 2.5 Particle size distribution of original BA aggregate. (Buritatum et al., 2022a)



Figure 2.6 Bottom ash waste from Mae Moh Electric power plant (EGAT)

BA can be used in civil engineering works such as aggregate replacement in concrete products, embankment fill, road construction, and reclamation work (H. Kim & Lee, 2015; Torkittikul, Nochaiya, Wongkeo, & Chaipanich, 2017). Previous studies also showed that marginal road materials can be improved by incorporating 10–25% BA. Such mixtures complying to the standards of the Thailand Department of Highways can then be used as a subbase. In Nigeria BA was successfully applied as a compacted material in unbound roads, the use of bottom ash envisaged application should therefore not result in any environmental impact (Abdulahi, 2009).

For each road construction materials BA was used in highway embankment construction offers an attractive alternative to disposal because substantial economic savings can be attained by the reduction of ash disposal costs and the conservation of natural soils and lands, pavement construction (Gautam et al., 2018; López-López et al., 2015; Yoo et al., 2016) and aggregate replacement in concrete pavement production (Arenas et al., 2011; Hannan et al., 2020). That is confirmation that both waste materials (RCA and BA) can be used in civil construction, especially in road construction materials from previous research. Almost all previous research has used cement-stabilized waste material is the trend of researchers and scientific to improve mechanical properties and studies to affect microstructure. However the past of cement-stabilized research are developed and improved concrete pavements also have several shortcomings, which include; high greenhouse gas emissions, low tensile and flexural strengths, and temperature susceptibility (Mohod & Kadam, 2016).

2.9 Natural rubber latex (NRL)

The BCG Model of economics is the current trend of the world wide, BCG Model is a holistic economic development that will develop the 3D economy simultaneously. The bio-economy system focuses on the use of biological resources to create added value by emphasizing the development of high-value products. Both economies are under the green economy, which is an economic development that focuses not only on economic development. However, it must be developed in tandem with social development and environmental protection in a balanced manner to ensure stability and sustainability at the same time. By transforming Thailand's advantages from biodiversity and culture into competitiveness through innovation to create a growing BCG economy that is globally competitive. Distribute income to communities and reduce inequality. Strong community, eco-friendliness, and sustainable development

The Southeast Asia region is the biggest natural rubber producer in the world. The production of rubber in this region is more than 50% of the total rubber production

worldwide. The top three countries include Thailand, Indonesia, and Vietnam. According to the statistical data in 2019 of the Rubber Authority of Thailand, Thailand had the largest natural rubber export, contributing approximately 38.82% of the world rubber market (Buritatum et al., 2021). (Figure 2.7) The fresh para rubber latex consists of 30–35% of dry natural rubber while the commercial grade has dry rubber content up to 60% (Krishnan, Joseph, & Roy, 2019). Several industries use para rubber because of its high flexibility, excellent insulation, plasticity, waterproofing, and impact resistance (Mark, 2007; G. Sukmak et al., 2020; Wu, Sun, Li, & Zeng, 2017). The NRL contained a dry rubber content of 52% and ammonia content of 0.7%. The rest of the content was water and water-soluble components at 47%. The studied NRL had a pH of 10.4, and its photo is provided in Figure 2,7



Figure 2.7 Natural rubber latex (NRL) (Suddeepong, Buritatum, et al., 2022)

Natural rubber latex (NRL) is a biopolymer from the *Hevea brasiliensis* tree. The raw state of NRL consists of polymer content (cis-1,4 - Polyisoprene) and water. The solid polymer content consists of approximately 94% rubber hydrocarbon and 6% non-rubber substances, such as phospholipids, and protein. The morphology evidence essentially indicates the rubber particles to be spherical in shape and with a random stuffing arrangement. This particle is typically surrounded by a layer of phospholipids and proteins. The existence of these non-rubber substances causes undesirable attributes, such as premature coagulation. In order to overcome the negative characteristic of NRL, it is usually modified with an additional substance. Ammonia is

an additive substance, which balances the charge between proteins and phospholipids, which results in the stability of the latex particles (Afiq & Azura, 2013; Herculano, de Queiroz, Kinoshita, Oliveira Jr, & Graeff, 2011; Horpibulsuk, Katkan, Sirilerdwattana, & Rachan, 2006; Nawamawat et al., 2011; Norhanifah, Nurulhuda, & Asrul, 2015; Rathnayake, Ismail, Baharin, Darsanasiri, & Rajapakse, 2012; Sakdapipanich, 2007).

In civil construction the application of NRL is used in building and road structures (base/subbase) has been reported by previous research. NRL has the potential to improve the viscosity and elastic recovery of the asphalt binder (Wen, Wang, Zhao, & Sumalee, 2017). However, the price of para rubber is very low due to the oversupply. In Thailand, the government encourages usage of para rubber latex as alternative materials for pavement (Kerarat et al., 2022). Road construction is important for developing countries, especially in Thailand, where the grown-up economy is usually a road network for product transportation, in Asian countries, such as Thailand, The Thailand Office of Transport and Traffic Policy and Planning uses NRL in road construction for alternative materials for pavement. A highway pavement is a structure consisting of layers of natural and processed materials above the natural ground level. The pavement structure includes subgrade, base/subbase, and surface layers. A pavement's primary function is to distribute the cyclic loads of vehicles from the top of the pavement to a larger area of the pavement structures without causing any damage to the subgrade. The aim of the pavement structure is to ensure that the transmitted wheel loads are sufficiently reduced so that they do not exceed the capacity of all the pavement layers. In other words, the pavement must be structurally adequate to withstand all stresses and maintain the cracking and deformation within tolerable limits (Hoy, Nhieu, et al., 2023). The basically sound properties of geopolymer could thus be improved with the incorporation of rubber latex. The NRL can improve the properties of geopolymer mortar incorporating NRL, with the setting time, water absorption, abrasion resistance, compressive strength, direct tensile strength, and bending strength. (Chindaprasirt & Ridtirud, 2020). The NRL used to improve indirect tensile resilient modulus (IT Mr), indirect tensile resilient fatigue, dynamic creep, rutting resistance, and skid resistance tests were used to assess the performance of asphalt concrete modified by BA. Its performance and technical characteristics were contrasted with traditional asphalt concrete. The study's findings will support the use of BA as a cleaner paving material, which is an environmentally friendly alternative to coal-fired power plants throughout the globe and EGAT. (Buritatum et al., 2022a)

2.10 Reference

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