INTISARI

Keberadaan tanah lempung ekspansif menyebabkan jalan-jalan mengalami kerusakan seperti bergelombang, retak-retak dan berlubang. Tanah tersebut berpotensi *swelling* sehingga mudah mengalami kembang dan susut. Selain itu, tanah juga mudah mengalami perubahan volume karena mengandung banyak kristal *montmorillonite* yang mempunyai gaya tarik kuat terhadap air sehingga partikel tanah terikat secara lemah. Metode perbaikan tanah ekspansif dapat dilakukan dengan stabilisasi kimiawi, yaitu pencampuran tanah dengan bahan seperti kapur, semen, *fly ash*, *bottom ash* atau bahan tambah lainnya. Pada penelitian ini bahan stabilisasi yang digunakan adalah *Fly Ash-Bottom Ash* (FABA). FABA dengan penambahan alkali aktivator berupa sodium hidroksida dan sodium silikat dapat berfungsi sebagai *binder* yang disebut pasta geopolimer. Penggunaan FABA pada penelitian ini bertujuan untuk mengurangi penumpukan limbah yang belum termanfaatkan dengan tepat dan menjadi alternatif pengganti semen yang produksinya menyebabkan emisi karbondioksida (pemanasan global).

Proses rancangan pasta geopolimer belum memiliki standar yang pasti sehingga pada penelitian ini menggunakan metode absolut volume. Kadar pasta geopolimer yang digunakan 12% dari berat kering tanah dengan variasi kadar *fly ash* 70% hingga 100% dan kadar *bottom ash* 0% hingga 30%. Proses pencampuran pasta geopolimer dan tanah dilakukan secara mekanis menggunakan *mixer*. Pengujian yang dilakukan pada penelitian ini adalah pengujian *initial setting time* dan kuat tekan untuk pasta geopolimer, sedangkan pengujian tanah yang distabilisasi dengan geopolimer yang dilakukan adalah sifat fisik dan mekanik, kandungan mineral, mikrostruktur, reaksi kimia dan kandungan logam berat pada tanah.

Hasil pengujian *initial setting time* dan kuat tekan pasta geopolimer diperoleh variasi optimum pasta geopolimer dengan sodium hidroksida konsentrasi 8M, perbandingan sodium silikat terhadap sodium hidroksida sebesar 0,5 dan perbandingan alkali aktivator terhadap binder sebesar 0,6. Hasil pengujian tanah yang distabilisasi dengan geopolimer menunjukkan peningkatan nilai *specific gravity*, peningkatan batas susut, menurunkan nilai batas cair dan indeks plastisitas, peningkatan gradasi butiran kasar tanah, peningkatan nilai kepadatan dan penurunan nilai kadar air serta peningkatan nilai UCS *soaked* (*Unconfined Compressive Strength soaked*). Oleh karena itu, dapat disimpulkan bahwa geopolimer FABA dapat menjadi alternatif pengganti semen. Hasil pengujian juga menunjukkan *Optimum Mix Design* (OMD) pada variasi 85% *fly ash* dan 15% *bottom ash* dengan peningkatan nilai CBR *soaked* (*California Bearing Ratio soaked*) lebih dari 6% dan penurunan nilai *swelling* kurang dari 2% yang memenuhi standar Bina Marga Tahun 2017. Hasil pengujian XRD (*X-ray Diffraction*) menunjukkan bahwa geopolimer dapat menurunkan kandungan mineral *montmorillonite* pada tanah dan hasil pengujian FTIR (*Fourier-Transform Infrared Spectroscopy*) menunjukkan reaksi kimia yang terbentuk antara tanah dan geopolimer membuat peningkatan kekuatan tanah. Hasil pengujian SEM-EDX (*Scanning Electron Microscope - Energy Dispersive X-Ray*) menunjukkan tanah geopolimer memiliki mikrostruktur yang relatif lebih padat dan tidak berongga. Pada pengujian AAS, hasil menunjukkan kandungan logam Pb (timbal), Cd (kadmium) dan Zn (seng) pada tanah geopolimer berada di bawah ambang batas yang diizinkan berdasarkan PP No. 22 Tahun 2021 yang berarti dapat digunakan sebagai *subgrade*. Namun, kandungan logam Cu (tembaga) dan Cr (kromium) berada di atas ambang batas yang mengindikasikan bahwa tanah geopolimer memerlukan adanya pengelolaan limbah non-B3 (non-Bahan Berbahaya dan Beracun).

Kata kunci: Geopolimer FABA; Kandungan Logam Berat; Kandungan Mineral; Mikrostruktur; Reaksi Kimia; Sifat Fisik; Sifat Mekanik; *Swelling*

ABSTRACT

The presence of expansive clay soil caused roads to experience damage such as waves, cracks, and potholes. This soil type had the potential for swelling, making it prone to expansion and shrinkage. Additionally, the soil was susceptible to volume changes due to its high content of montmorillonite crystals, which exerted a strong tensile force against water, leading to weakly bound soil particles. Expansive soil improvement methods can be carried out through chemical stabilization, which involves mixing the soil with materials such as lime, cement, fly ash, bottom ash, or other additives. In this research, the stabilization material used was Fly Ash-Bottom Ash (FABA). FABA, with the addition of alkali activators in the form of sodium hydroxide and sodium silicate, functioned as a binder known as geopolymer paste. The use of FABA in this study aimed to reduce the accumulation of waste that had not been properly utilized and to serve as an alternative to cement, whose production contributes to carbon dioxide emissions and global warming.

The design process of geopolymer paste did not have a definitive standard, so this research utilized the absolute volume method. The geopolymer paste content used was 12% of the dry weight of the soil, with variations in fly ash content ranging from 70% to 100% and bottom ash content from 0% to 30%. The mixing process of geopolymer paste and soil was conducted mechanically using a mixer. The tests conducted in this study included initial setting time and compressive strength tests for the geopolymer paste. For the geopolymer-stabilized soil, the tests performed were assessments of physical and mechanical properties, mineral content, microstructure, chemical reactions, and heavy metal content in the soil.

The results of testing the initial setting time and compressive strength of the geopolymer paste indicated that the optimum variation was achieved with a sodium hydroxide concentration of 8M, a sodium silicate to sodium hydroxide ratio of 0.5, and an alkali activator to binder ratio of 0.6. The test results for soil stabilized with geopolymer showed several improvements: an increase in specific gravity, an increase in shrinkage limit, a decrease in liquid limit and plasticity index, an improvement in soil coarse grain gradation, an increase in density, a decrease in moisture content, and an increase in soaked UCS (Unconfined Compressive Strength). Thus, it can be concluded that FABA geopolymer can serve as an alternative to cement. The test results also indicated the Optimum Mix Design (OMD) at a variation of 85% fly ash and 15% bottom ash, which demonstrated an increase in the soaked CBR (California Bearing Ratio) value to more than 6% and a decrease in swelling to less than 2%, meeting the Bina Marga 2017 standard. XRD (X-ray Diffraction) test results showed that geopolymers could reduce the content of montmorillonite minerals in the soil, while FTIR (Fourier-Transform Infrared Spectroscopy) results indicated that the chemical reaction formed between the soil and geopolymers increased soil strength. SEM-EDX (Scanning Electron Microscope - Energy Dispersive X-ray) results demonstrated that geopolymer-stabilized soil had a relatively denser and less porous microstructure. In the AAS (Atomic Absorption Spectroscopy) test, the results revealed that the metal contents of Pb (lead), Cd (cadmium), and Zn (zinc) in the geopolymer soil were below the permissible thresholds based on PP No. 22 of 2021, indicating that it could be used as subgrade material. However, the metal contents of Cu (copper) and Cr^{+6} *(chromium) were above the thresholds, suggesting that the geopolymer soil requires management as non-hazardous and non-toxic waste (non-B3).*

Keywords: *FABA Geopolymer; Heavy Metal Contents; Mineral Contents; Microstructure; Chemical Reactions; Physical Properties; Mechanical Properties; Swelling*