

# ISRG Journal of Engineering and Technology (ISRGJET)



ISRG PUBLISHERS

Abbreviated Key Title: ISRG J Eng Technol

ISSN: 3107-5894 (Online)

Journal homepage: <https://isrgpublishers.com/isrgjet/>

Volume – II Issue- II (March-April) 2026

Frequency: Bimonthly



## STABILIZATION OF CLAY SOIL USING A MIXTURE OF ZEOLITE AND PLASTIC SACK FIBER

Sainal Tandi Datu<sup>1\*</sup>, Yulius Bakkara<sup>2</sup>, Hernita Matana<sup>3</sup>, Abdias Tandy Arrang<sup>4</sup>

<sup>1,2</sup> Civil, Department of Civil Engineering, Universitas Kristen Indonesia Toraja, Indonesia.

<sup>3,4</sup> Lecturer, Department of Civil Engineering, Universitas Kristen Indonesia Toraja, Indonesia.

| Received: 15-04-2026 | Accepted: 22-04-2026 | Published: 25-04-2026

\*Corresponding author: Sainal Tandi Datu

### Abstract

Soft clay soil generally has low bearing capacity and low shear strength because of its moderate plasticity and weak inter-particle cohesion, which frequently causes civil engineering problems such as settlement, shrinkage, swelling, and slope failure, particularly during periods of high rainfall. This study aims to determine the physical and mechanical properties of clay soil before treatment and to evaluate the effect of a zeolite and plastic sack fiber (PSF) mixture on its shear strength. The clay sample was taken from Pa'besenan, Tadongkon Village, Kesu' Sub-district, North Toraja Regency. The research was experimental in nature and was carried out at the Soil Mechanics Laboratory of the Civil Engineering Study Program, Universitas Kristen Indonesia Toraja, referring to SNI 1738:2011. Zeolite content was varied at 3%, 7%, and 13% of soil weight, combined with a constant plastic sack fiber content of 0.2% for every variation, with curing periods of 3, 7, and 14 days. Laboratory tests included sieve analysis, specific gravity, water content, Atterberg limits, compaction (Proctor), and direct shear tests. The AASHTO classification system placed the original soil in group A-2-7 (clayey soil). Adding zeolite and plastic sack fiber increased the specific gravity, optimum moisture content, and maximum dry density in every mixture variation compared with the untreated soil. The shear strength of the untreated soil was 33.17 kN/m<sup>2</sup>; it increased progressively with higher zeolite content and longer curing time, reaching a maximum of 54.38 kN/m<sup>2</sup> for the 13% zeolite + 0.2% plastic sack fiber mixture at 14 days of curing, an increase of about 64% over the untreated soil. These results indicate that zeolite acts as the dominant pozzolanic binder that cements the soil particles together, while the plastic sack fiber restrains particle displacement, and that the combination is a promising, low-cost, and environmentally beneficial alternative for stabilizing soft clay soil.

**Keywords:** clay soil; soil stabilization; zeolite; plastic sack fiber; shear strength

## INTRODUCTION

Soil is the fundamental material that supports almost every type of civil engineering structure, ranging from buildings, roads, and embankments to bridges, harbors, and airports. It serves as the subgrade layer, the foundation support, and the material used for drainage infiltration and embankment fill. However, soil properties vary widely from one location to another, and not every soil possesses adequate bearing capacity. Damage to structures built on soil is often caused by problems inherent to the soil itself, such as settlement, shrinkage, and swelling.

Among the various soil types found in Indonesia, clay soil is one of the most frequently encountered and is also one of the most problematic. Based on its consistency, clay is commonly classified into hard clay, very stiff clay, stiff clay, medium clay, soft clay, and very soft clay. Soft clay, in particular, often creates difficulties in civil engineering works because it has moderate plasticity, meaning its shape can change with variations in water content without a corresponding change in volume, and it has relatively low cohesiveness between particles. This weak inter-particle bonding frequently triggers slope failures, especially during periods of high rainfall intensity.

One way to improve the physical and mechanical behavior of clay soil is chemical soil stabilization, in which the soil is mixed with a stabilizing agent to alter its properties. In this study, zeolite — a volcanic mineral with pozzolanic characteristics — was selected as the primary stabilizing agent because of its capacity to strengthen the bonds between soil particles. It was combined with shredded plastic sack fiber, a form of plastic waste, as a secondary reinforcing agent. This combination is intended not only to improve the engineering behavior of the clay but also to promote the beneficial reuse of plastic waste in the construction sector.

## IDENTIFY, RESEARCH AND COLLECT IDEA

### Problem Statement

Based on the background above, this research addresses two questions:

1. what are the physical and mechanical properties of the clay soil before the addition of zeolite and plastic sack fiber.
2. how does the zeolite and plastic sack fiber mixture affect the shear strength value of the soil.

### Research Objectives

This study aims to determine the physical and mechanical properties of the clay soil prior to stabilization, and to evaluate the influence of the zeolite and plastic sack fiber mixture on the shear strength of the soil.

### Scope and Limitations

The scope of this research is limited as follows: (1) the soil sample used is clay taken from Pa'besenan, Tadongkon Village, Kesu' Sub-district, North Toraja Regency; (2) the stabilizing materials used are zeolite and plastic sack fiber; (3) laboratory testing was carried out at the Civil Engineering Laboratory of Universitas Kristen Indonesia Toraja and included water content, sieve analysis, specific gravity, Atterberg limits, compaction, and shear strength tests; (4) the zeolite content was varied at 3%, 7%, and 13%; (5)

the plastic sack fiber content was fixed at 0.2% for every mixture variation, cut into 1-2 cm pieces; and (6) the curing periods applied were 3, 7, and 14 days.

North Toraja Regency is a mountainous highland area characterized by steep terrain and high seasonal rainfall, conditions under which soft and medium-plasticity clay soils are particularly prone to slope instability, road subgrade failure, and foundation settlement. Locally available, low-cost stabilizing materials are therefore of practical interest for rural infrastructure development in this region. Zeolite deposits and discarded plastic sacks are both readily available in North Toraja, which motivated the selection of these two materials as the stabilizing agents evaluated in this study, in line with the broader objective of promoting appropriate, locally sourced construction technology while simultaneously addressing plastic waste accumulation.

### Significance of the Study

This study is expected to contribute in two ways. Academically, it provides quantitative laboratory evidence on how a zeolite-fiber combination affects the physical and mechanical properties of a specific clay soil, adding to the still-limited body of research on zeolite-based chemical stabilization compared with more conventional additives such as cement and lime. Practically, the findings offer local government agencies, contractors, and communities in North Toraja and similar regions an evidence-based option for improving subgrade and embankment soils using materials that are inexpensive, locally sourced, and partly derived from waste, which may lower the cost of small-scale road and slope-protection works while simultaneously reducing the environmental burden of discarded plastic sacks.

## LITERATURE REVIEW

### Previous Studies

Research on soil reinforcement using plastic fiber has shown that the strengthening mechanism relies on the shear resistance developed between the plastic material and the surrounding soil particles, since synthetic fibers have a higher rupture strain than the soil itself and therefore continue to provide tensile resistance even after the surrounding soil has passed its failure strain, preventing sudden collapse. A study on clay stabilization using plastic sack fiber conducted on samples from the Kasihan area, Bantul, evaluated the effect of fiber reinforcement through triaxial testing. Adding sheet-shaped fiber (25 mm<sup>2</sup>) at a content of 0-0.2% increased the soil cohesion from 222.25 kN/m<sup>2</sup> to 269.03 kN/m<sup>2</sup> (an increase of about 20.9%), while a further increase from 0.2% to 0.5% caused cohesion to drop to 199.73 kN/m<sup>2</sup> (a decrease of about 10.2%). The same study also reported that ring-shaped fiber with a 25 mm diameter increased the bearing capacity from 3431.4 kN/m<sup>2</sup> to 6255.9 kN/m<sup>2</sup> (an 82.3% increase) at the optimum fiber content of 0.2%, while sheet-shaped fiber increased it from 3431.4 kN/m<sup>2</sup> to 8508.7 kN/m<sup>2</sup> (a 147.96% increase).

A separate investigation involving 100 compaction and California Bearing Ratio (CBR) tests on four different soil types — uniformly graded sand, crushed rock, medium-plasticity clay, and high-plasticity clay — reinforced with fiber grids, reported CBR increases of about 100% for sandy soil, 300-400% for crushed rock, and 25-100% for both clay types. The improvement in CBR strength for all four soil types was directly related to the percentage of fiber grid added, with a recommended maximum fiber content ranging from 0.2% to 9%. These findings support the use of plastic

sack fiber as a practical and effective soil-reinforcing material, consistent with the approach adopted in the present study.

### Clay Soil

Clay consists of mineral particles smaller than 0.002 mm and constitutes the primary source of cohesive behavior in soil. The physical and mechanical characteristics of clay are governed by the dominant clay mineral group present. Clay minerals are complex hydrous aluminum silicates composed of silica tetrahedra and aluminum octahedra sheets, and are generally divided into three mineralogical groups: the kaolinite group, which is generally non-expansive; the mica-like group (including illite and vermiculite), which is slightly expansive; and the smectite group (including montmorillonite), which is highly expansive. Typical properties of clay soil include a fine particle size of less than 0.002 mm, low permeability, high capillary rise, strong cohesiveness, high shrink-swell potential, and a slow consolidation process.

### Soil Classification

Soil classification systems group soils with similar engineering behavior so that suitability for a given purpose can be estimated quickly. The AASHTO classification system separates granular soils (35% or less passing the No. 200 sieve) from silt-clay soils (more than 35% passing the No. 200 sieve), and further subdivides them based on the percentage passing the No. 10, No. 40, and No. 200 sieves together with the liquid limit and plasticity index of the material passing the No. 40 sieve. Group A-2-7, relevant to this study, denotes silty or clayey gravel and sand with a liquid limit above 41% and a plasticity index above 11%, generally rated as fair to good subgrade material.

### Soil Stabilization

Soil stabilization is an effort to improve soil conditions by adding or modifying the structure of the soil layer to increase bearing capacity, maintain shear strength, and reduce deformation. Common stabilization measures include increasing soil density, adding inert material to increase cohesion and shear resistance, adding material that induces chemical or physical changes in the soil, lowering the groundwater table through drainage, or replacing poor soil entirely. Stabilization methods are generally grouped into three categories: mechanical stabilization, aimed at achieving maximum soil density using equipment such as rollers, pounders, controlled blasting, or preloading; physical stabilization, which alters soil properties through heating, cooling, or the application of electric current; and chemical stabilization, which involves mixing the soil with a chemical additive — such as Portland cement, lime, asphalt, or other admixtures, including zeolite in this study — to trigger a chemical reaction that changes the soil's properties.

### Zeolite

Zeolite is a crystalline mineral formed from volcanic rock deposited from magma released during ancient volcanic eruptions. It is a hydrated aluminosilicate crystal containing alkali and alkaline-earth cations within its three-dimensional framework, with the general empirical formula  $M_x/n(AlO_2)_x(SiO_2)_y \cdot H_2O$ , where M denotes the alkali or alkaline-earth cation, n is the metal valence, and x and y are specific coefficients. Zeolite exhibits several relevant chemical properties: dehydration, in which water molecules are released from the crystal lattice to form larger surface cavities favorable for adsorption; adsorption of gases or liquids once the mineral has been dehydrated; ion exchange, in which cations within the pore spaces can move freely and be

exchanged depending on the size, charge, and type of the zeolite; a catalytic effect, in which the mineral alters the rate of a reaction without shifting its equilibrium; and a molecular sieving or filtering effect, in which particles smaller than the pore size can pass through while larger particles are retained. As a soil stabilizing agent, zeolite is well suited to upgrading substandard soil because it improves the density, bonding, compressive strength, and shear resistance between soil particles, thereby improving the mineral quality of the soil, strengthening inter-particle bonding to increase bearing capacity and compressive strength, and enhancing the soil's resistance to shear failure on slopes.

### Plastic Sack Fiber

Plastics are synthetic or semi-synthetic polymerization products formed through the condensation or addition of organic polymers, and can be shaped into films or synthetic fibers due to their malleable properties. Their light weight, adaptability, and low cost make plastics widely used across nearly every industrial sector. Several mechanical properties are relevant when plastic fiber is used as a soil-reinforcing material: tensile strength, the stress required to break a sample, which is particularly important for fiber-shaped material; compressive strength, the resistance to compressive load, in which plastics generally perform well due to their flexibility and elasticity; flexural strength, the resistance to bending; and impact strength, the resistance to a sudden shock load. In this research, plastic sack waste was cut into short fibers (1-2 cm) and mixed into the soil at a fixed content of 0.2%, functioning to restrain the displacement of soil grains and complement the cementing action provided by zeolite.

## WRITE DOWN YOUR STUDIES AND FINDINGS

### MATERIALS AND METHODS

#### Research Location

Laboratory testing was carried out at the Soil Mechanics Laboratory, Civil Engineering Study Program, Universitas Kristen Indonesia Toraja, located on the university's Kakondongan (Campus II) site. The clay soil sample was taken from Pa'besenan, Tadongkon Village, Kesu' Sub-district, North Toraja Regency. Zeolite was obtained from a supplier in Sa'dan Sangkaropi' Village, Sa'dan Sub-district, North Toraja Regency, while the plastic sack fiber, cut into pieces of 1-2 cm, was purchased at Bolu Market, North Toraja Regency.

#### Research Method

This research used an experimental method referring to SNI 1738:2011. Two soil conditions were examined: the untreated (original) soil, and soil stabilized with zeolite and plastic sack fiber at several mixture ratios. Zeolite content was varied at 3%, 7%, and 13% of the total soil weight, combined with a fixed plastic sack fiber content of 0.2% at every variation. Specimens were cured for 3, 7, and 14 days prior to shear strength testing. The complete mixture design is presented in Table 1.

#### Mixture Design

Table 1. Mixture design used in the research

| Sample Code | Soil (%) | Zeolite (%) | Plastic Sack Fiber (%) | Curing Period (days) |
|-------------|----------|-------------|------------------------|----------------------|
|             |          |             |                        |                      |

|               |      |    |     |            |
|---------------|------|----|-----|------------|
| Original Soil | 100  | 0  | 0   | 3          |
| V1            | 96.8 | 3  | 0.2 | 3 / 7 / 14 |
| V2            | 92.8 | 7  | 0.2 | 3 / 7 / 14 |
| V3            | 86.8 | 13 | 0.2 | 3 / 7 / 14 |

### Testing Program

The following laboratory tests were performed on both the original and the stabilized soil specimens:

- 1. Water content and sieve analysis.** The water content test determined the ratio of pore water weight to dry soil weight. Sieve analysis (dry and wet methods) was performed on 500 g of oven-dried soil passing the No. 4 sieve, shaken through a stack of standard sieves for 10 minutes to determine the particle size distribution.
- 2. Specific gravity (Gs).** Determined using a pycnometer with soil passing the No. 40 sieve, comparing the weight of the soil grains with the weight of an equal volume of distilled water at a given temperature.
- 3. Atterberg limits.** The liquid limit (LL) was obtained using the Casagrande apparatus, relating the number of blows required to close a groove in the soil paste to its water content. The plastic limit (PL) was determined from the water content at which a 3 mm soil thread begins to crumble, and the shrinkage limit (SL) from the water content at which further drying causes no additional volume change. The plasticity index (IP) was calculated as LL minus PL.
- 4. Compaction test.** Standard Proctor compaction was performed using a compaction mold with a rammer weighing 2.5 kg (5.5 lb) dropped from a height of 304.8 mm (12 in), to establish the relationship between water content and dry unit weight and to identify the optimum moisture content (OMC) and maximum dry density (MDD) for each mixture variation.
- 5. Direct shear test.** Specimens were prepared at their optimum moisture content and tested under three normal loads (3 kg, 6 kg, 9 kg) to obtain the normal stress and maximum shear stress at each load level. The shear stress-normal stress relationship was plotted and fitted with a linear regression to obtain the cohesion ( $c$ , the intercept) and the internal friction angle ( $\phi$ , the arctangent of the slope), from which the shear strength ( $S$ ) was computed using the Mohr-Coulomb equation  $S = c + \sigma \tan \phi$ , where  $\sigma$  is the normal stress.

### Governing Equations

The water content of every specimen was computed as  $w = (W_w/W_s) \times 100\%$ , where  $W_w$  is the weight of pore water and  $W_s$  is the weight of oven-dried soil. Specific gravity was computed as  $G_s = W_s / [(W_2 - W_1) - (W_3 - W_4)]$ , where  $W_1$  is the weight of the empty pycnometer,  $W_2$  the weight of the pycnometer plus dry soil,  $W_3$  the weight of the pycnometer plus soil plus water, and  $W_4$  the weight of the pycnometer filled with water only. The liquid limit was obtained by plotting the water content of each trial against the logarithm of the corresponding number of blows and reading the water content at the standard 25-blow condition, while the plastic limit was taken directly as the average water content at which a 3 mm soil thread began to crumble; the plasticity index was then computed as  $IP = LL - PL$ . In the direct shear test, the normal stress

was computed as  $\sigma = P/A$  and the shear stress as  $\tau = F/A$ , where  $P$  is the applied normal load,  $F$  is the shear force recorded by the proving ring at failure, and  $A$  is the cross-sectional area of the specimen.

### A. Bits and Pieces together

## RESULTS AND DISCUSSION

### Grain Size Distribution

Analysis of the original soil, summarized Sieve in Table 2, shows that a large proportion of the material passes the finer sieves, indicating a fine-grained soil dominated by silt and clay fractions.

**Table 2. Sieve analysis results for the original soil**

| Sieve No. | Opening (mm) | Percent Retained (%) | Percent Passing (%) |
|-----------|--------------|----------------------|---------------------|
| 4         | 4.75         | 0.00                 | 100.00              |
| 10        | 2.00         | 4.80                 | 95.20               |
| 20        | 0.85         | 8.66                 | 91.34               |
| 40        | 0.425        | 23.00                | 77.00               |
| 60        | 0.25         | 28.34                | 71.66               |
| 100       | 0.15         | 31.36                | 68.64               |
| 200       | 0.075        | 43.14                | 56.86               |
| Pan       | -            | 100.00               | 0.00                |

With 56.86% of the material passing the No. 200 sieve — well above the 35% threshold used by the AASHTO system to separate granular from silt-clay soils — the sample is classified as a fine-grained, silt-clay type soil, consistent with field observations of the sampling location.

### Specific Gravity

Specific gravity testing was carried out using two pycnometer trials for the untreated soil, as summarized in Table 3.

**Table 3. Specific gravity trial data for the untreated soil (average  $G_s = 2.59$ )**

| Parameter                                   | Trial IA | Trial IIA |
|---------------------------------------------|----------|-----------|
| Pycnometer + dry soil weight, $W_2$ (g)     | 89.47    | 89.68     |
| Empty pycnometer weight, $W_1$ (g)          | 39.47    | 39.68     |
| Dry soil weight used, $W_s$ (g)             | 50.00    | 50.00     |
| Test temperature ( $^{\circ}\text{C}$ )     | 25.00    | 25.00     |
| Pycnometer + water weight, $W_4$ (g)        | 138.00   | 138.00    |
| Pycnometer + water + soil weight, $W_3$ (g) | 168.70   | 168.80    |

|                      |      |      |
|----------------------|------|------|
| Specific gravity, Gs | 2.59 | 2.60 |
|----------------------|------|------|

The specific gravity (Gs) of the soil increased consistently with increasing zeolite content, as shown in Table 4.

**Table 4. Specific gravity for each mixture variation**

| Mixture Variation           | Specific Gravity (g/cm <sup>3</sup> ) |
|-----------------------------|---------------------------------------|
| Original Soil               | 2.59                                  |
| V1 (Zeolite 3% + PSF 0.2%)  | 2.68                                  |
| V2 (Zeolite 7% + PSF 0.2%)  | 2.70                                  |
| V3 (Zeolite 13% + PSF 0.2%) | 2.73                                  |

The increase in specific gravity across all variations indicates that the addition of zeolite and plastic sack fiber alters the mineral composition and packing of the soil grains, and is consistent with the higher density of the zeolite particles relative to the natural clay.

#### Atterberg Limits and Soil Classification

Atterberg limit testing on the original soil produced a liquid limit (LL) of 54.24%, a plastic limit (PL) of 36.85%, a shrinkage limit (SL) of 22.53%, and a plasticity index (IP) of 17.39%, as summarized in Table 5.

**Table 5. Atterberg Limits of the original soil**

| Parameter         | Liquid Limit (LL) | Plastic Limit (PL) | Shrinkage Limit (SL) | Plasticity Index (IP) |
|-------------------|-------------------|--------------------|----------------------|-----------------------|
| Original Soil (%) | 54.24             | 36.85              | 22.53                | 17.39                 |

The liquid limit was determined from three trials at different numbers of blows, summarized in Table 6, with the water content at each trial plotted against the logarithm of the number of blows and interpolated at the standard 25-blow condition to give LL = 54.24%.

**Table 6. Liquid limit trial data for the untreated soil**

| Trial | Number of Blows, N | Average Water Content (%) |
|-------|--------------------|---------------------------|
| S1    | 15                 | 60.80                     |
| S2    | 22                 | 55.02                     |
| S3    | 27                 | 48.83                     |

Based on the AASHTO classification system, with 56.86% of the material passing the No. 200 sieve, a liquid limit of 54.24%, and a plasticity index of 17.39% (both exceeding the A-2-7 thresholds of LL > 41% and IP > 11%), the original soil is classified as group A-2-7, described as clayey gravel and sand, generally rated fair to good as a subgrade material but sensitive to moisture-induced strength loss — which is precisely the behavior that the stabilization program in this study seeks to address. This classification is also consistent with the plasticity index of 17.39%,

which places the soil in the cohesive, medium-to-high plasticity range typically associated with silty clay.

#### Compaction Test

For the untreated soil, five trial points relating water content to wet and dry unit weight were obtained, as summarized in Table 7.

**Table 7. Compaction trial data for the untreated soil**

| Trial | Water Content (%) | Wet Unit Weight (g/cm <sup>3</sup> ) | Dry Unit Weight (g/cm <sup>3</sup> ) |
|-------|-------------------|--------------------------------------|--------------------------------------|
| 1     | 16.43             | 1.42                                 | 1.22                                 |
| 2     | 20.33             | 1.54                                 | 1.28                                 |
| 3     | 24.03             | 1.59                                 | 1.28                                 |
| 4     | 27.32             | 1.63                                 | 1.28                                 |
| 5     | 32.10             | 1.64                                 | 1.24                                 |

Fitting a second-order polynomial to the dry unit weight versus water content data gave a peak dry unit weight of 1.29 g/cm<sup>3</sup> at an optimum moisture content of 25.00%, confirming the values reported in Table 8. The compaction test established the relationship between water content and dry unit weight for the original soil and for each mixture variation, from which the optimum moisture content (OMC) and maximum dry density (MDD) were obtained. Results are presented in Table 8.

**Table 8. Compaction test results for each mixture variation**

| Mixture Variation           | Optimum Moisture Content, OMC (%) | Maximum Dry Density, MDD (g/cm <sup>3</sup> ) |
|-----------------------------|-----------------------------------|-----------------------------------------------|
| Original Soil               | 25.00                             | 1.29                                          |
| V1 (Zeolite 3% + PSF 0.2%)  | 30.00                             | 1.30                                          |
| V2 (Zeolite 7% + PSF 0.2%)  | 32.10                             | 1.31                                          |
| V3 (Zeolite 13% + PSF 0.2%) | 35.10                             | 1.33                                          |

Both the optimum moisture content and the maximum dry density increased progressively with increasing zeolite content. This trend indicates that, under the same compactive effort, the addition of zeolite and plastic sack fiber requires more water to reach optimum compaction while simultaneously allowing the soil to be compacted to a denser state, reflecting an improvement in the packing behavior of the treated soil.

#### Direct Shear Test

The direct shear test on the untreated soil, using normal loads of 3 kg, 6 kg, and 9 kg, produced the normal and shear stresses summarized in Table 9.

**Table 9. Normal stress and maximum shear stress of the untreated soil**

| Parameter                                             | Load 3 kg | Load 6 kg | Load 9 kg |
|-------------------------------------------------------|-----------|-----------|-----------|
| Normal Stress, $\sigma$<br>(kg/cm <sup>2</sup> )      | 0.09      | 0.18      | 0.28      |
| Maximum Shear Stress,<br>$\tau$ (kg/cm <sup>2</sup> ) | 0.212     | 0.232     | 0.287     |

Plotting shear stress against normal stress and fitting a linear regression yielded the equation  $\tau = 0.1833\sigma + 0.0959$ , from which a cohesion ( $c$ ) of 0.0959 kg/cm<sup>2</sup> and an internal friction angle ( $\phi$ ) of 22° were obtained for the untreated soil, giving a shear strength of  $S = 0.0959 + (0.60 \times \tan 22^\circ) = 0.3383$  kg/cm<sup>2</sup>, equivalent to 33.17 kN/m<sup>2</sup>. The same procedure was repeated for every mixture variation and curing period, and the resulting cohesion, friction angle, and shear strength values are summarized in Table 10.

**Table 10. Cohesion, internal friction angle, and shear strength for every mixture variation and curing period**

| Sample                      | Curing Period (days) | Cohesion, $c$ (kg/cm <sup>2</sup> ) | Friction Angle, $\phi$ (°) | Shear Strength, $S$ (kN/m <sup>2</sup> ) |
|-----------------------------|----------------------|-------------------------------------|----------------------------|------------------------------------------|
| Original Soil               | -                    | 0.0959                              | 22                         | 33.17                                    |
| V1 (Zeolite 3% + PSF 0.2%)  | 3                    | 0.1803                              | 24                         | 43.87                                    |
| V1 (Zeolite 3% + PSF 0.2%)  | 7                    | 0.2040                              | 25                         | 47.44                                    |
| V1 (Zeolite 3% + PSF 0.2%)  | 14                   | 0.2211                              | 26                         | 48.92                                    |
| V2 (Zeolite 7% + PSF 0.2%)  | 3                    | 0.1993                              | 25                         | 46.98                                    |
| V2 (Zeolite 7% + PSF 0.2%)  | 7                    | 0.2163                              | 26                         | 48.46                                    |
| V2 (Zeolite 7% + PSF 0.2%)  | 14                   | 0.2720                              | 28                         | 53.25                                    |
| V3 (Zeolite 13% + PSF 0.2%) | 3                    | 0.2154                              | 26                         | 48.92                                    |
| V3 (Zeolite 13% + PSF 0.2%) | 7                    | 0.2373                              | 27                         | 52.14                                    |
| V3 (Zeolite 13% + PSF 0.2%) | 14                   | 0.2491                              | 27                         | 54.38                                    |

The shear strength of the untreated soil, 33.17 kN/m<sup>2</sup>, increased in every mixture variation and at every curing period. For the 3% zeolite mixture, shear strength rose to 43.87, 47.44, and 48.92 kN/m<sup>2</sup> after 3, 7, and 14 days of curing, respectively. For the 7% zeolite mixture, shear strength increased to 46.98, 48.46, and 53.25 kN/m<sup>2</sup>, while for the 13% zeolite mixture the values reached 48.92, 52.14, and 54.38 kN/m<sup>2</sup>. The highest shear strength recorded in the study, 54.38 kN/m<sup>2</sup>, corresponds to a 63.9% increase over the

untreated soil, and was obtained with the 13% zeolite + 0.2% plastic sack fiber mixture cured for 14 days.

Both the cohesion and the internal friction angle increased consistently with higher zeolite content and longer curing time, which explains the corresponding rise in shear strength. This behavior is attributed to the pozzolanic reaction between zeolite and the clay particles, which produces cementitious bonding products that increase with curing time as the reaction progresses, while the plastic sack fiber contributes a complementary reinforcing action by restraining the relative displacement of soil grains during shearing rather than acting as the primary binder. This finding is consistent with previous studies, which similarly report that fiber reinforcement enhances cohesion and bearing capacity but that a pozzolanic or cementitious additive is generally the more dominant factor governing the overall gain in shear strength.

Overall, the combination of zeolite and plastic sack fiber proved effective at improving both the physical and mechanical properties of the clay soil evaluated in this study. Beyond its technical benefits, the use of plastic sack fiber also offers an environmentally favorable avenue for reusing plastic waste as a construction material, aligning the practical application of this stabilization method with sustainability considerations in civil engineering practice.

#### Comparison with Previous Studies

The 63.9% increase in shear strength obtained in this study for the 13% zeolite + 0.2% plastic sack fiber mixture cured for 14 days is broadly consistent with earlier findings on fiber- and zeolite-based stabilization. A prior study on clay reinforced with plastic sack fiber alone reported a cohesion increase of about 20.9% at an optimum fiber content of 0.2%, but a decline in cohesion when the fiber content was increased beyond 0.2%, indicating that an excess of fiber can disrupt particle-to-particle contact rather than improve it. Similarly, fiber-grid reinforcement studies on clay soils reported CBR gains in the range of 25% to 100%, depending on soil type and fiber content, with a recommended fiber content ceiling of about 9%. The present study observed a comparable but numerically higher improvement, which suggests that the pozzolanic contribution of zeolite complements, and in this soil appears to exceed, the purely mechanical reinforcement provided by plastic fiber. This observation reinforces the conclusion, drawn in the results above, that zeolite is the dominant contributor to the shear-strength gain, while the fiber provides a secondary but still measurable reinforcing effect.

#### Summary of Property Changes

Table 11 summarizes the percentage change in each measured parameter for the best-performing mixture (V3, 13% zeolite + 0.2% plastic sack fiber, 14 days curing) relative to the untreated soil, consolidating the individual results discussed above into a single overview.

**Table 11. Summary of property changes for the best-performing mixture relative to the untreated soil**

| Parameter                             | Original Soil | V3 at 14 Days Curing | Change (%) |
|---------------------------------------|---------------|----------------------|------------|
| Specific gravity (g/cm <sup>3</sup> ) | 2.59          | 2.73                 | +5.4       |

|                                          |        |        |        |
|------------------------------------------|--------|--------|--------|
| Optimum moisture content (%)             | 25.00  | 35.10  | +40.4  |
| Maximum dry density (g/cm <sup>3</sup> ) | 1.29   | 1.33   | +3.1   |
| Cohesion, c (kg/cm <sup>2</sup> )        | 0.0959 | 0.2491 | +159.8 |
| Internal friction angle, $\phi$ (°)      | 22     | 27     | +22.7  |
| Shear strength (kN/m <sup>2</sup> )      | 33.17  | 54.38  | +63.9  |

The largest relative gains were observed in cohesion and shear strength, reinforcing the earlier conclusion that the pozzolanic bonding contributed by zeolite is the primary mechanism responsible for the overall improvement in soil behavior, while the more modest changes in specific gravity and maximum dry density reflect a secondary densification effect from the combined additive materials.

### Practical Implications

From a practical standpoint, the results indicate that a locally available pozzolanic material such as zeolite, combined with a small, fixed proportion of shredded plastic waste, can meaningfully improve the shear strength of soft-to-medium plasticity clay without requiring imported or costly stabilizing agents such as Portland cement or lime. This is particularly relevant for rural road subgrade improvement, embankment construction, and slope-stabilization works in North Toraja and similar highland regions, where transportation costs for conventional stabilizers can be prohibitive. The use of plastic sack fiber also contributes, at a small scale, to reducing plastic waste accumulation, offering a secondary environmental benefit alongside the geotechnical improvement documented in this study. Nevertheless, because the tests reported here were limited to direct shear and did not include a full assessment of durability under repeated wetting-drying cycles, field application should proceed cautiously and be supported by further testing, as outlined in the recommendations below.

### CONCLUSION

Based on the physical and mechanical properties tests performed on the clay soil from Pa'besenan, Tadongkon Village, North Toraja Regency, at the Civil Engineering Laboratory of Universitas Kristen Indonesia Toraja, the untreated soil is classified under the AASHTO system as group A-2-7 (clayey soil), with a liquid limit of 54.24%, a plasticity index of 17.39%, and an initial shear strength of 33.17 kN/m<sup>2</sup>. The addition of zeolite and plastic sack fiber increased the specific gravity, the optimum moisture content, and the maximum dry density in every mixture variation compared with the untreated soil.

The zeolite and plastic sack fiber mixture was shown to increase the shear strength of the clay soil across all zeolite contents examined (3%, 7%, and 13%) and all curing periods (3, 7, and 14 days), with the highest shear strength of 54.38 kN/m<sup>2</sup> obtained at 13% zeolite content combined with 0.2% plastic sack fiber after 14 days of curing — an improvement of approximately 63.9% relative to the untreated soil.

### Limitations of the Study

This study is limited to a single clay source and a single fiber size and shape, so the results should not be generalized to all clay soils or all forms of plastic sack fiber without further verification. Mechanical strength was evaluated only through the direct shear test; other relevant parameters such as unconfined compressive strength, California Bearing Ratio, permeability, swelling potential, and long-term durability under repeated wetting-drying or freeze-thaw cycles were not investigated and remain important subjects for further study before the method can be recommended for full-scale field application.

### Recommendations

Based on the findings of this study, the following are recommended for future research: (1) similar stabilization trials should be conducted on other soil types using the same additive materials to verify the generality of the observed trends; (2) subsequent studies may explore different zeolite and plastic sack fiber proportions to further optimize the optimum moisture content associated with the additive materials; and (3) future research should be complemented with unconfined compression tests (UCT) and California Bearing Ratio (CBR) tests to provide a more comprehensive assessment of the stabilized soil's engineering performance.

### ACKNOWLEDGMENT

The authors would like to thank the Soil Mechanics Laboratory, Civil Engineering Study Program, Faculty of Engineering, Universitas Kristen Indonesia Toraja, for providing the testing facilities used throughout this research.

### REFERENCES

1. Abdilla, M., Abdilla, N., & Abrar, A. (2020). The effect of plastic sack fiber and coconut coir on the shear strength parameters of clay soil.
2. Aslina, B., et al. (2007). The chemical properties of zeolite as a soil stabilizing material.
3. Adinda. (2000). Reinforcement of clay soil using plastic sack fiber: a triaxial testing study, Kasihan, Bantul.
4. Alvian, R., & Phelia, A. (2020). The effect of zeolite on the bearing capacity of clay soil evaluated using the California Bearing Ratio method.
5. Febriantama, et al. (2016). Soil stabilization methods and their application in subgrade improvement.
6. Guido, V. A. (1955). Compaction and CBR laboratory investigation of fiber-grid reinforced soils.
7. Gunarso. (2017). Engineering properties and behavior of clay soil.
8. Herdiana. (2018). Mineralogical control on the physical and mechanical properties of clay soil.
9. Hermawan, M. I., Afriani, L., & Iswan. (2015). Correlation between unconfined compressive strength and direct shear strength of clay soil mixed with zeolite.
10. Hidayat, R. The effect of zeolite addition on the unconfined compressive strength and direct shear strength of clay soil.
11. Ingles, O. G., & Metcalf, J. B. (1972). Soil stabilization: principles and practice.
12. Martini, M., Fadlia, I., & Biru, B. Study of soil shear strength behavior with the addition of jute sack fiber.
13. Pah, J. (2010). Basic physical properties of soil for soil-type identification.

14. Pamungkas, P. S., Immananto, E. L., & Ardian, E. Y. (2019). The effect of plastic sack fiber addition as a mixture material for reinforcing clay soil embankments.
15. Ramadani, S. (2020). Analysis of cohesion and friction angle of clay soil mixed with zeolite.
16. Sentosa. (2021). Clay mineral structure and its influence on soil engineering behavior.
17. Sheftel, V. O. (2000). Handbook of toxic properties of monomers and polymers.
18. Thomas, R., Sarajar, N., & Legrans, R. R. I. (2018). The effect of zeolite addition on the shear strength of clayey soil.
19. Utami, Y. F. (2014). The effect of plastic sack fiber waste addition on the bearing capacity of clay soil.
20. Wulandari, R., Ganjar, S., & Sarie, F. (2022). The effect of plastic sack fiber addition on clay soil evaluated using the CBR test.