International Journal of Applied Science and Engineering

# Sustainable soil stabilization using marble dust waste on high plasticity soils: Physical and mechanical properties study

**Woelandari Fathonah *, Rama Indera Kusuma, Enden Mina, Nida Dalilah Hasanah**

*Department of Civil Engineering, University of Sultan Ageng Tirtayasa, Cilegon City 42435, Indonesia*

## ABSTRACT

Soils with high plasticity tend to have strong plastic properties and easily deform when exposed to shear forces. These soils are often a problem in construction because of their ability to cause deformation and cracks in structures. Therefore, high plasticity soils require stabilization to increase their bearing capacity and reduce the risk of damage to the structure. A sample of this soil-stabilizing is marble dust waste which is normally generated in large quantities and has been discovered to hurt the environment. Therefore, this study focuses on determining the effect of marble dust waste addition as a stabilizer on soil's physical and mechanical properties. The physical properties tests carried out were the physical properties tests for compaction, Atterberg limit, specific gravity and particle size distribution of the original soil, the mixed soil, and the marble powder's chemical properties. The chemical properties test of marble powder consists of XRF and SEM-EDX tests. Based on the characterization results, marble powder is dominated by CaO compounds, the morphology of the particles is agglomerated and irregular shape. The mechanical test conducted was a CBR with the marble powder waste varied at 0%, 7% and 27% for a curing time of 0, 3 and 7 days. The results showed that adding the material reduced the plasticity index (PI) value from 29.24% to 10.56% and increased the CBR value by 15.50% by applying a 7% variation over a 7-day cure time. Additionally, it's important to note that the CBR standard for subgrade specifications typically requires a value exceeding 6%. This indicates that the curing time affects the increment in the CBR value and that marble powder wastes can be used as an additive for sustainable soil stabilization.

***Keywords:*** CBR, High plasticity soil, Marble dust waste, Soil stabilization, Sustainable, XRD, SEM-EDX test.

**OPEN ACCESS**

**Received:** May 1, 2023
**Revised:** September 1, 2023
**Accepted:** September 9, 2023

**Corresponding Author:**
Woelandari Fathonah
woelandari@untirta.ac.id



**Publisher:**
Chaoyang University of Technology
**ISSN:** 1727-2394 (Print)
**ISSN:** 1727-7841 (Online)

## 1. INTRODUCTION

Budhu (2011) explains that high-plasticity soils have a high PI, namely PI > 20%. High-plasticity soils tend to have strong plastic properties and easily deform when exposed to shear forces. This soil type generally has a high clay content and shortage of sand and organic content. Bell (2013) and Uge (2017) explains that high plasticity soils are often found in tropical and subtropical areas and are often a problem in construction because of their ability to cause deformation and cracking of structures. Therefore, high-plasticity soils often require stabilization to increase their bearing capacity and reduce the risk of damage to the structure.

The research location in Kasemen District, Banten where there are potholes and bumpy roads due to erosion. Dynamic Cone Penetrometer (DCP) testing was carried out to determine the strength of the soil at that location, and the results showed that the average value of soil strength was only 1.97%. Based on Binamarga regulations, the required effective CBR value for the subgrade is above 6%. This shows that the soil in that location has weak strength, and it is necessary to take action so that the road can be used safely, one of which is by improving the soil, namely soil stabilization.

Murmu et al. (2020) and Kumar and Harika (2021) researched soil stabilization using fly ash to improve the mechanical properties of the soil, such as its strength and durability, through the addition of certain materials, such as a combination of fly ash and slag by Fathonah et al. (2020), cement slag by Fathonah et al. (2019), Kusuma et al. (2020), Rind et al. (2020), gypsum by Kusuma et al. (2018) and Latifi et al. (2018), lime by Negi et al. (2013), Barbero et al. (2021), soil stabilization using cement, bitumen and other additives with the ability to bind soil particles by Rashidi et al. (2018). The abundant waste materials from the marble industry are one of the additives usually used for soil stabilization. Waheed et al. (2021) explained that careless waste disposal by marble processing factories could cause severe environmental damage, such as dust pollution, which is increasingly endangering the surrounding community. The industrial presence of marble and its abundant waste is one solution for utilizing marble powder waste as a cheaper, more sustainable soil stabilizing additive. Previous studies by Danish et al. (2021) showed that marble powder wastes could be used as raw material to produce building materials, bricks by Saboya et al. (2007), ceramics by Acchar et al. (2006), and modified polymer mortar by Hwang et al. (2008), while coarse marble lime can be used as filler by Karaşahin and Terzi (2007) and aggregate substitute for asphalt pavements by Akbulut and Gürer (2007). Utilizing marble powder waste as a soil stabilizing agent can be considered a sustainable solution because this waste is usually produced in large quantities by the marble processing industry and can cause environmental problems. By using this waste as an additive to increase soil carrying capacity, waste can be reused, reducing discharges to the environment and reducing the need for other additives which may be more harmful to the environment. The research highlights various studies on soil stabilization methods using different additives, while emphasizing the potential of utilizing marble powder waste as a sustainable soil stabilizer due to its abundance and environmental benefits.

Edora and Adajar (2021) is a study of XRF analysis from PT. Sucofindo Jakarta showed that the main component of marble powder waste includes 52.69% lime compound and 1.62% silica, making it usable as an additive for chemical soil stabilization. Saygili (2015) explains that applying these wastes as construction materials can provide environmental benefits. Moreover, Deboucha et al. (2020) reported that soil stabilization using marble dust and ceramic waste combined with some ordinary Portland cement was quite effective as an alternative to road sub-base. Setyono et al. (2018) also used marble powder in an expansive clay case study in the Citra Land area of Surabaya and found an increase in the CBR value at 2.79, 3.33, 4.00, 4.77, 5.58 and 6.47% for percentage variations of 5%, 10%, 15%, 20% and 25%, respectively. An Atterberg limit test also indicates a reduction in the PI value from 39.83% to 9.09% in the highest percentage variation of marble powder.

Wardana (2009) also used marble powder as an added material for clay in Bali and showed that the values of specific gravity, liquid limit (LL) and PI decreased with the addition of 3%, 6%, 9%, 12% and 15% of marble while the plastic limit (PL) value increased. Moreover, the highest design in the CBR test with the addition of 9% marble powder and the compaction energy of 56 strokes was found to be 9%. Babu and Mary (2017) studied adding marble dust for soil stabilization in India at 3%, 6%, 9%, 12% and 15% variations with 3, 7 and 14 days of curing times. The results showed that the CBR values were optimum at 9% marble dust levels, with 8.83% recorded at 0 days, 10.91% in 3 days, 13.52% in 7 days and 14.55% in 14 days. Another study by Abdulla and Majeed (2021) on expansive soil stabilization using marble powder waste at 10%, 20% and 30% variations showed that an increase in the marble powder waste reduced the potential for swelling and shrinkage of the soil. Saygili (2015) also researched the effect of using marble powder waste at 0%–30% for soil stabilization on soil weight and found that marble powder waste could increase shear strength and reduce soil shrinkage. In addition, marble powder was used as a soil stabilizing agent, which decreased the LL, PI, and shrinkage index but raised the liquid and shrinkage limit, according to Agrawal and Gupta (2011). According to Muthu and Tamilarasan (2015), it was noted that the PL value increased while the LL value decreased from 70% to 55%. Waheed et al. (2021) studied the effectiveness of marble powder waste varied at 5%, 10% and 15% of soil weight. They were used as a soil stabilizers (CL-ML) through physical and mechanical tests. The results showed that the marble powder waste added was able to increase unsoaked CBR value up to 10%, while the value at seven days of curing increased from 6.5% to 11.3%. This shows that curing time has a significant influence on the CBR value. Based on this background, this research was carried out to analyze soil stabilization using a mixture of marble powder waste varied at 0%, 7%, 17% and 27% for curing times of 0, 3 and 7 days. Involving tests of the physical, mechanical and chemical properties of marble dust to deeply understand its characteristics and its influence on soil in enhancing bearing capacity and reducing plasticity.

## 2. MATERIALS AND METHODS

### 2.1 Material

The materials used in this study were disturbed soil and marble powder. In this study, disturbed soil samples were taken from a depth of 30 cm in the village of Masjid Priyayi, Kasemen District, Serang City, Banten Province, Indonesia. Soil sampling at a depth of 30 cm is considered disturbed because at the depth, the soil has been influenced by human activities, erosion, compaction, or other factors that can alter the soil properties. Soil samples were put in the oven to reach the oven-dry condition to be used for some tests. Some soil samples form large lumps, so they must be pounded first with a rubber hammer before testing, as shown in Fig. 1. and the marble powder used in this study is shown in Fig. 2.

**Fig. 1.** Oven-dry soil samples

**Fig. 2.** Marble powder waste

## 2.2 Method

The chemical, mechanical and physical properties of marble powder in soil were investigated in this study. Among the soil physical tests done were those for particle size distribution, specific gravity, the Atterberg limit, compaction, and the USCS for soil classification. SEM-EDX (Scanning Electron Microscope- Energy Dispersive X-Ray) analysis and XRF (X-ray Fluorescence) analysis were used to analyze the chemical characteristics of marble powder. The CBR unsoaked test for mechanical characteristics was conducted and was examined in a lab. The marble powder wastes varied at 0%, 7%, 17% and 27% during cure durations of 0, 3 and 7 days, which is a significant point to notice. The selection of specific percentage of marble dust (0%, 7%, 17% and 27%) in the study is likely based on the need to explore a range of concentrations to understand how different levels of marble dust affect the physical and mechanical properties of the soil.

### 2.2.1 Sample Preparation

The original sample was obtained from the study location as disturbed soil mixed with marble powder and water based on the variations and curing time presented in Table 1.

**Table 1.** The proportion of specimen mixture

| No | Samples | Curing (days) |
|---|---|---|
| 1 | Natural soil | 0, 3, 7 |
| 2 | Soil + 7% marble powder | 0, 3, 7 |
| 3 | Soil + 17% marble powder | 0, 3, 7 |
| 4 | Soil + 27% marble powder | 0, 3, 7 |

The percentage of marble dust in a sample is typically determined through a process of mixing a known quantity of marble dust with the original material (e.g., soil) and then calculating the percentage based on the weight of the added marble dust relative to the total weight of the mixture.

### 2.2.2 Specific Gravity

An essential factor in describing the physical characteristics of soil is specific gravity. This variable assesses a soil's density or weight in relation to the specific gravity of water at a certain temperature and pressure. The SNI 1964-2008 Standard is referred to in specific gravity testing. It is crucial knowledge about the impact of marble waste powder on the physical characteristics of soil that is obtained by measuring the specific gravity of soil using various concentrations of marble waste powder. Understanding the features of the mixture and choosing the right quantities for intended soil stabilization applications may be made easier with the help of this information.

### 2.2.3 Standard Proctor Compaction Test

The standard proctor compaction test was conducted in line with ASTM D 698-70 and SNI 1942-2008 to obtain information on the optimum moisture content (OMC) and maximum dry density (MDD). The first step was to determine the compaction parameters of the original soil followed by those of each variation of the mixed soil which was later used to calculate the required soil and water to be added to each mixture. It is crucial to note that the amount of water that was utilized at the optimal level was what was noted for each change.

### 2.2.4 Atterberg Limit Test

The LL and PL were the main emphasis of the Atterberg limit test, which was also carried out in accordance with ASTM 4318 and SNI 1966-2008. It is significant to remember that the water content at the intersection of the liquid and plastic conditions is the LL. The water content and soil volume typically decrease as a result, and the grain spreads. The PL, on the other hand, was established using a sample that was twisted until it cracked to verify that it reached 3 mm in diameter. The PL refers to the water content at the point where plastic and semi-solid materials converge. The sample was weighed both before and after the 24-hour baking period.

### 2.2.5 California Bearing Ratio (CBR) Test

In order to assess the potential strength of the subgrade, sub-base, and foundation materials as well as the recycled materials for roads and airport runway pavements, CBR was evaluated in accordance with ASTM D1883-16 and SNI 1744-2012. CBR is defined as the difference between the standard load at the same penetration depth and speed and the penetration load of a particular type of material. The values are generally selected at 0.1-inch penetration and this indicates the test needs to be repeated when the value is at 0.2-inch penetration but the value can be used when a similar result is obtained after the test. In Fig. 3, the CBR test on soil samples is displayed. The marble powder waster was added at 7%, 17% and 27%, and a total of 36 samples were needed for the unsoaked CBR test in this study. It is important to point out that each 1 specimen consists of 3 molds for 10, 25 and 65 impacts, and the CBR value was calculated based on 95% MDD.

**Fig. 3.** CBR test on soil samples

### 2.2.6 XRF (X-Ray Fluorescence)

Marble powder XRF analysis was carried out based on identifying and enumerating the X-ray characteristics from the photoelectric effect event. The type of equipment used is the Niton XL3t 500 Portable. XRF testing involves several stages, starting with sample preparation, which requires grinding and shaping the sample into a uniform form. The XRF instrument is then calibrated using calibration standards to ensure the accuracy of the test results. Subsequently, the sample is placed under the X-ray beam generated by the instrument, and the instrument detects the XRF produced by the sample. From this XRF spectrum, the XRF instrument identifies the elements contained in the sample and measures their concentrations.

### 2.2.7 SEM-EDX (Scanning Electron Microscope-Energy Dispersive X-Ray)

Surface morphology analysis of marble powder was carried out using SEM, and elemental composition using EDX. The types of equipment used are SEM (Zeiss EVO 10 Scanning Electron Microscope) and XRD (D8 ADVANCE ECO X-ray Diffraction). SEM-EDX (Scanning Electron Microscope-Energy Dispersive X-Ray) testing involves several crucial stages. Firstly, the sample to be analyzed is prepared and treated as needed, including coating with a conductive layer if necessary. Subsequently, the sample is placed in the SEM vacuum chamber, where an electron beam is used to scan and generate surface images of the sample. Meanwhile, the EDX detector measures the spectrum of energy-dispersed X-rays produced when electrons interact with the sample. From this spectrum, information about the elemental composition of the sample can be quantitatively analyzed. The result is high-detail surface images of the sample along with elemental composition data that are valuable for material research and analysis. Morphological analysis of marble powder samples was carried out using a scanning electron microscope. Marble powder samples are prepared first by coating Au; at 20 mA so that the sample becomes conductive. SEM analysis was carried out at magnifications 500, 1000, 2000 and 5000 X with a voltage of 5 kV.

## 3. RESULTS AND DISCUSSION

### 3.1 Physical Properties of Origin Soil

Physical properties are summarized in the following Table 2. This soil is categorized as organic clay with medium to high plasticity, symbolized by OH about the USCS classification system based on the data in the table. The original soil PI value is included in the high plasticity category. Hence, the soil at the study site needs to be stabilized to reduce the PI and increase soil strength. This research is related to a previous study by Mina and Kusuma (2016), Nujid et al. (2019), Sinha and Iyer (2020) and Mina et al. (2021).

**Table 2.** Physical properties of origin soil

| No | Properties | Unit | Value |
|---|---|---|---|
| 1 | Specific gravity (Gs) | | 2.65 |
| 2 | LL | % | 62 |
| 3 | PL | % | 32.76 |
| 4 | PI | % | 29.24 |
| 5 | OMC | % | 24 |
| 6 | MDD | $g/cm^3$ | 1.40 |
| 7 | a. Fine particle | % | 52.20 |
| | b. Course particle | | 47.80 |

## 3.2 Properties of Marble Powder Waste

### 3.2.1 XRF Analysis

Based on the results of XRF analysis, the chemical elements of the marble powder in this study had a high calcium oxide (CaO) content of 94.13%, a silicon dioxide ($SiO_2$) content of 1.53% and an aluminum oxide ($Al_2O_3$) of 0.13%. The chemical element composition of marble powder is shown in Table 3. Amadi (2014), Cui et al. (2018) and Adeyanju and Okeke (2019) explain that the proportions of $SiO_2$, CaO and $Al_2O_3$ in added materials are responsible for the effectiveness of soil strength. CaO is a compound needed in a chemical process with clay, producing high calcium ions that can bind and surround clay particles. As a result, it can reduce the water drag and affects the CBR value, soil density and swelling of clay soils; this research is related to a previous study by Bilgin et al. (2012) and Al-Huda and Gunawan (2013).

**Table 3.** Chemical element composition of marble powder waste

| No | Element | (%) |
|---|---|---|
| 1 | CaO | 94.13 |
| 2 | Magnesium oxide (MgO) | 2.85 |
| 3 | $SiO_2$ | 1.53 |
| 4 | $Al_2O_3$ | 0.13 |
| 5 | Ferric oxide ($Fe_2O_3$) | 0.30 |
| 6 | Others | 1.06 |

### 3.2.2 SEM-EDX Analysis

Based on the results of the SEM test on marble powder, the morphology and particle size can be seen with magnifications of 500, 1000, 2000 and 5000 X, as shown in Fig. 4. The morphology of marble powder has irregular particle shapes, agglomerates. Saygili (2015) reported that adding marble powder to clay samples is a filler and increases the coarser particles. The results of the EDX test at the firing point (spectrum 1, spectrum 2, spectrum 3 and spectrum 4) as shown in Fig.5.

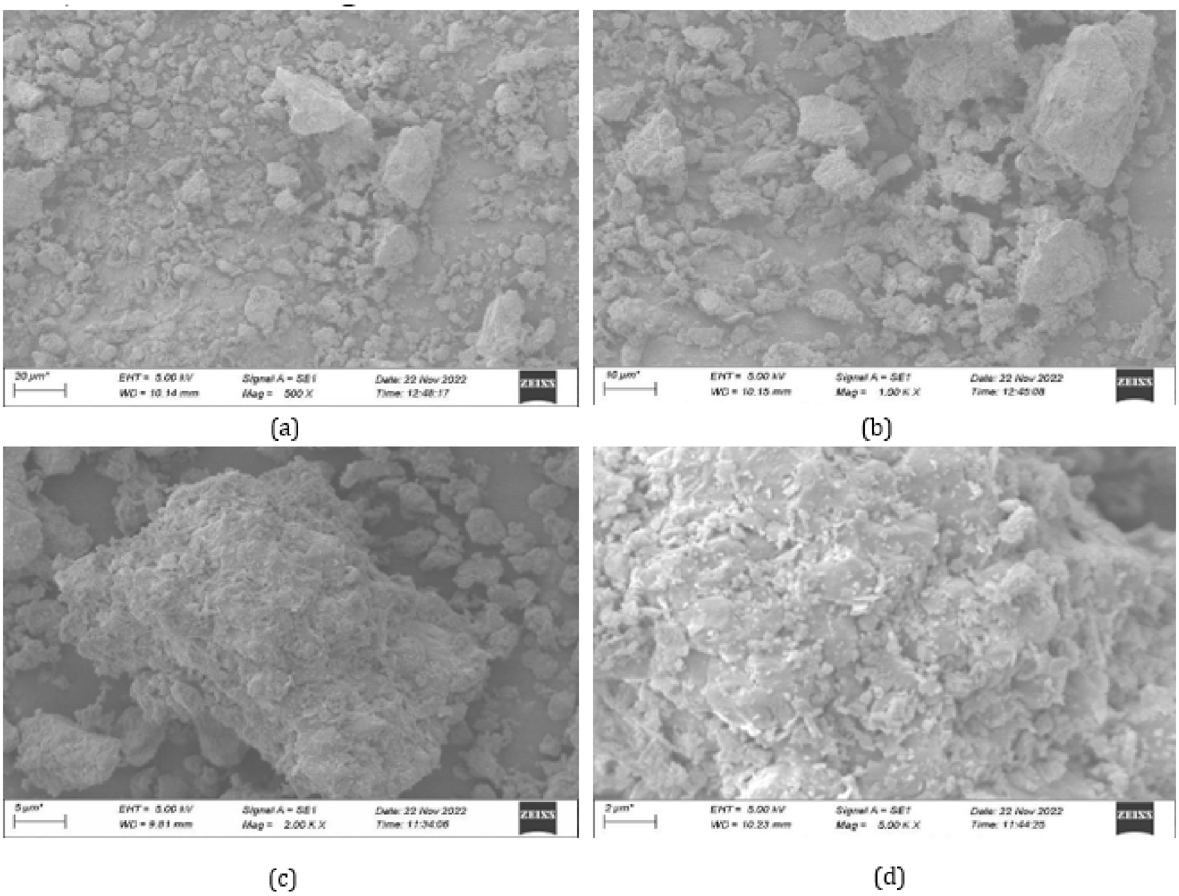


**Fig. 4.** SEM observation of marble powder waste: (a) Mag: 500 X; (b) Mag: 1000 X; (c) 2000 X; (d) 5000 X

*Fathonah et al., International Journal of Applied Science and Engineering,* 20(4), 2023126

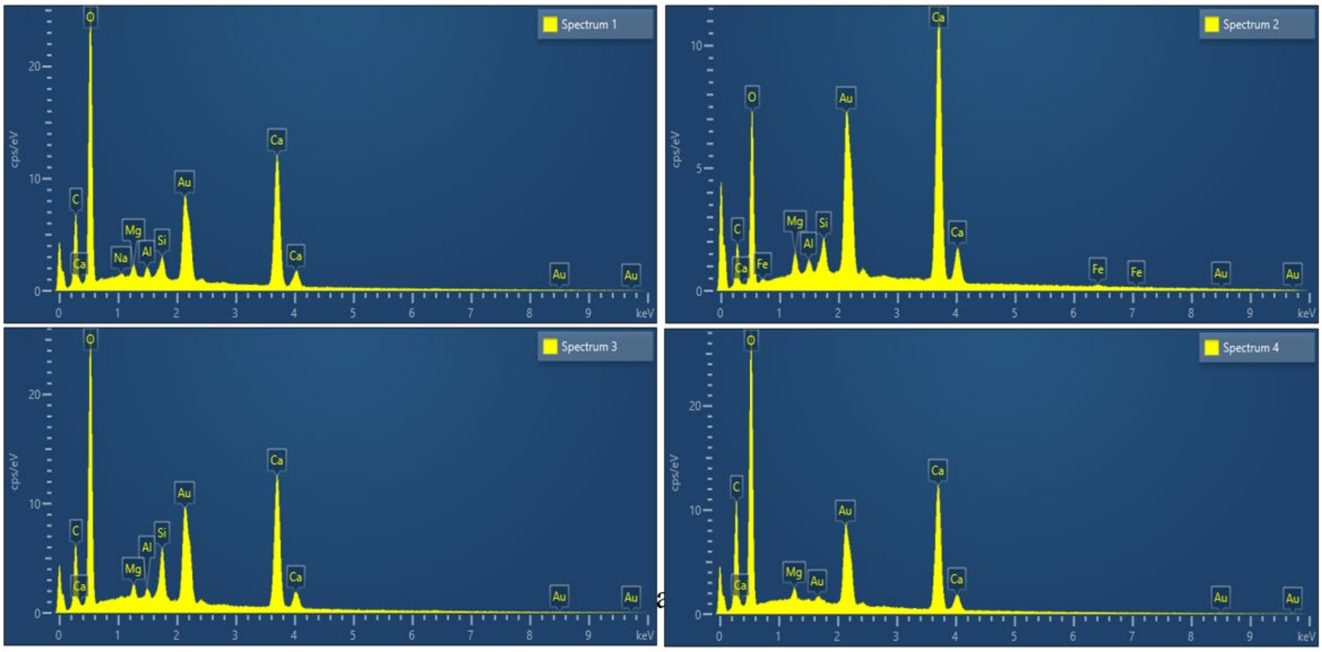


**Fig. 5.** Results of EDX analysis of marble powder

Fig. 4 shows that the morphology of marble powder has irregular particle shapes and agglomerates. Adding marble powder to the clay sample functions as a filler and increases the size of the coarser particles because marble powder has a larger grain size characteristic compared to clay, so the addition of marble powder can increase the particle size of the mixture and improve the physical and mechanical properties of soil. This research is related to a previous study by Jalal et al. (2021) and Bheel et al. (2023).

Fig. 5 shows that marble powder contains elements such as calcium (Ca), carbon (C) and oxygen (O), the concentration of which can affect the physical and mechanical properties of a mixture of soil and marble powder.

## 3.3 Physical and Mechanical Properties of Mixed Soil

### 3.3.1 Effect of Waste Marble Powder on Specific gravity

The physical and mechanical characteristics of the soil-marble powder mixture are significantly influenced by the specific gravity of the marble powder, which is a significant parameter. Table 4 displays the specific gravity test findings.

**Table 4.** Specific gravity test results

| Marble powder waste (%) | Specific gravity |
|---|---|
| 0 | 2.65 |
| 7 | 2.62 |
| 17 | 2.60 |
| 27 | 2.58 |

Table 4 demonstrates that when the marble powder variety in the combination increases, the specific gravity of the marble powder falls. This drop in specific gravity is consistent with earlier research's findings.

The specific gravity of soil mixes may be impacted by the addition of additives, according to earlier study by Minhas (2016). The specific gravity of the mixture may drastically drop when the quantity of additions, such as marble powder, is increased. This is because the specific gravity of marble powder, which separates the two components, is lower than that of the original soil. The MDD of the mixture may be affected by the change in specific gravity, which may also have an effect on the mechanical characteristics of the combination.

### 3.3.2 Effect of Waste Marble Powder on Optimum Moisture Content (OMC) and Maximum Dry Density (MDD)

According to each % of waste marble powder, the OMC and MDD values are displayed in Fig. 6. An increase in the waste percentage was found to be closely linked to an increase in the OMC value, which went from 24% to 29%. This is due to the segmentation or binding that made the soil mixture clump and increase the soil's water content. As the proportion of marble powder was raised, the MDD decreased from 13.73 $kN/m^3$ to 12.85 $kN/m^3$, which was related to the clumping response that caused a more substantial change in the total soil volume and an increase in the number of pores. This is in line with the findings of Deboucha et al. (2020) that adding 5% fine-grained marble powder led to an increment in the OMC value from 10.78% to 12.96% while the MDD value decreased. A similar finding was also reported by Waheed et al. (2021) that the

OMC value increased from 15.70% to 18.22% while the MDD value decreased as the variation of marble powder increased from 18.34 kN/m$^3$ to 17.85 kN/m$^3$. This was reported to be due to the flocculated and agglomerated clay particles, caused by the cation exchange reaction, occupying the space, which led to increased pore volume based on the reduction in the weight-volume ratio.

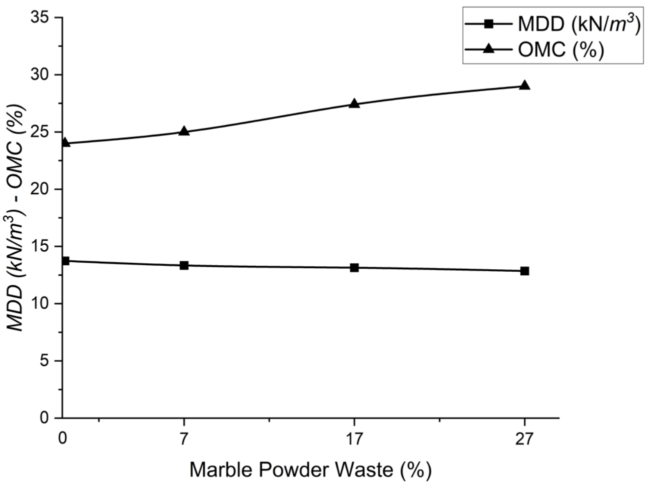


**Fig. 6.** Effect of waste marble powder on OMC and MDD

Fig. 6 shows that adding marble powder to the soil can affect the geotechnical properties of the soil, including the MDD. The difference between the physical properties of the soil and marble powder can explain this. Marble powder has different characteristics from the soil, namely having a finer particle shape and lower density. Due to the gap between the marble powder particles that penetrate the soil, there will be an increase in soil volume and a decrease in soil density when there is an addition of marble powder. The density of the soil lowers as marble powder is added at a higher percentage because more room is created. The MDD also decreases as a result of the decrease in soil density. Because marble powder includes a lot of CaO, the amount of ideal water in the soil increases when it is added. Calcium hydroxide ($Ca(OH)_2$) is created when CaO and water combine. Because $Ca(OH)_2$ may bind water, more $Ca(OH)_2$ is produced in the soil when marble powder is applied. Therefore, the greater the percentage of marble powder added to the soil, the optimum water content also increases. This research is related to a previous study by Al-naje et al. (2020) and Zada et al. (2023).

### 3.3 Effect of Waste Marble Powder on Plasticity Index (PI)

The results of the Atterberg limits test, comprising the liquid and plastic limit, are displayed in Fig. 7. The PI was calculated concurrently by deducting the LL value from the PL value. It was discovered that an increase in the marble powder waste led to a reduction in the LL value and PI from 29.24% to 10.56% but an increment in the PL value. The findings also showed that the PI value was 13.61% at 17% marble was variation, categorized as medium plasticity. This is in line with the previous study by Agrawal and Gupta (2011) that using marble powder as a soil stabilizing agent reduced the LL, PI, and shrinkage index but increased the liquid and shrinkage limits. It was also reported by Jain et al. (2020) that the factors influencing the behavior of soil stabilized by marble powder waste include mineralogy composition, chemical element contents of marble powder and soil type. Okagbue and Onyeobi (1999) and Saygili (2015) reported that the geotechnical properties of clay soils changed after adding marble powder and curing time reduces swelling.

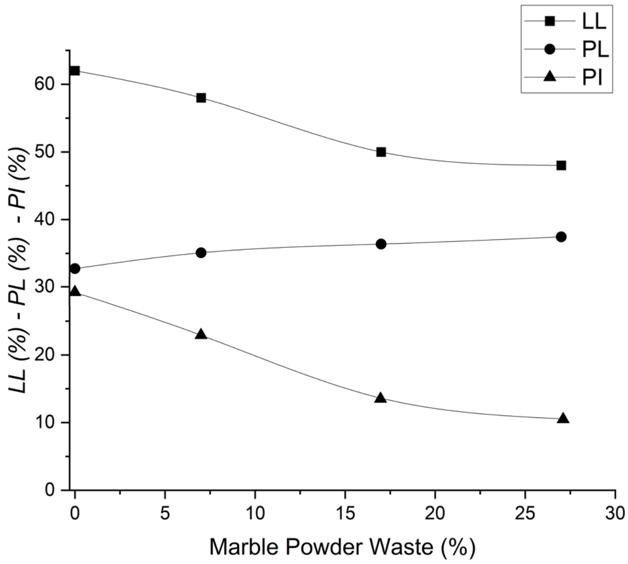


**Fig. 7.** Effect of waste marble powder on PI

Fig. 7 demonstrates how adding marble powder into the soil can lower its PI. The PI decreases as the percentage of marble powder added increases. This is because marble powder contains a lot of CaO, which can react with water in the soil to form $Ca(OH)_2$, which is alkaline in nature. These compounds will accelerate the binding reaction between soil particles and water particles, thus increasing soil aggregates' stability and reducing soil's tendency to deform when exposed to shear forces. As the percentage of marble powder increases, the clay content in the mixture decreases, so the PI decreases. This research is related to a previous study by Jain and Jha (2020) and Nawaz et al. (2020).

### 3.4 Effect of Waste Marble Powder on CBR

Fig. 8 shows the results of the CBR test conducted by varying the marble powder waste at 0%, 7%, 17% and 27% for curing times of 0, 3 and 7 days at 95% of the MDD. It was discovered that the CBR value increased at 7% but reduced afterward. The value was also observed to have increased from 11.00% to 15.50% at 7% marble powder waste during seven days of curing. This result is supported by a previous study by Waheed et al. (2021) that added marble powder waste increased the CBR value up to 10% and from 6.50% to 11.30% at seven days of curing. In addition, the formation of cement minerals in the reaction between clay-marble powder can increase bonding between the clay particles, thereby increasing the shear strength after being mixed with marble powder waste and curing time has the effect of increasing the shear strength, this research related with the previous study by Okagbue and Onyeobi (1999) and Saygili (2015).

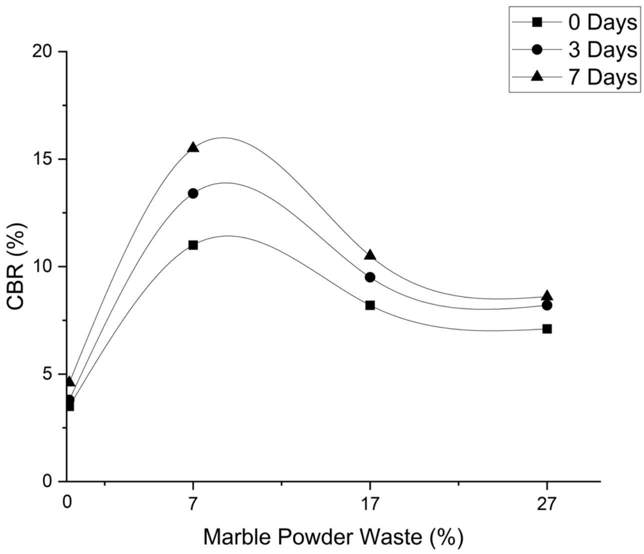


**Fig. 8.** Effect of waste marble powder on CBR

Fig. 8 shows the optimal variation in CBR values is achieved at a marble powder percentage of 7%, with a curing time of seven days, resulting in a CBR value of 15.50%. This can be attributed to the filler effect of marble powder, which enhances the strength and stability of the soil mixture. Additionally, it's important to note that the CBR standard for subgrade specifications typically requires a value exceeding 6%.

## 4. CONCLUSION

This study demonstrates that the utilization of marble powder waste can lead to a significant increase in the CBR value while simultaneously reducing the PI value. The CBR value exhibited an increase at a 7% variation of the waste and a subsequent decrease beyond this percentage. Notably, the highest CBR value of 15.50% was achieved with a 7% variation of marble powder waste after seven days of curing. This highlights the substantial impact of curing time on the CBR value, with the PI value decreasing from 29.24% to 10.56% as the content of marble powder waste increased. Consequently, it can be concluded that marble powder waste holds potential as a sustainable subgrade stabilizer in the construction industry, offering positive environmental benefits.

## REFERENCES

Abdulla, R., Majeed, N. 2021. Enhancing engineering properties of expansive soil using marble waste powder. Iraqi Geological Journal, 54, 43–53.

Acchar, W., Vieira, F.A., Hotza, D. 2006. Effect of marble and granite sludge in clay materials. Materials Science and Engineering A, 419, 306–309.

Adeyanju, E.A., Okeke, C.A. 2019. Clay soil stabilization using cement kiln dust. IOP Conference Series: Materials Science and Engineering, 640.

Agrawal, V., Gupta, M. 2011. Expansive soil stabilization using marble dust. International Journal of Earth Sciences and Engineering, 4, 59–62.

Akbulut, H., Gürer, C. 2007. Use of aggregates produced from marble quarry waste in asphalt pavements. Building and Environment, 42, 1921–1930.

Al-Huda, N., Gunawan, H. 2013. Pemanfaatan Limbah Karbit Untuk Meningkatkan Nilai CBR Tanah Lempung Desa Cot Seunong (172 G). Konferensi Nasional Teknik Sipil 7 (KoNTekS 7).

Al-naje, F.Q., Abed, A.H., Al-Taie, A.J. 2020. A review of sustainable materials to improve geotechnical properties of soils. Al-Nahrain Journal for Engineering Sciences, 23, 289–305.

Amadi, A.A. 2014. Enhancing durability of quarry fines modified black cotton soil subgrade with cement kiln dust stabilization. Transportation Geotechnics, 1, 55–61.

Babu, S., Mary, S. 2017. Soil stabilization using marble dust. International Journal of Civil Engineering and Technology (IJCIET), 8, 1706–1713.

Barbero, D., Serraiocco, L., Maroni, A., Peyrot, S. 2021. A laboratory methodological proposal for "Geotechnical lime stabilization of A-4 soils". Journal of Geotechnical Engineering, 8, 1–11.

Bell, F.G. 2013. Engineering properties of soils and rocks. Elsevier. Butterworth-Heinemann Ltd, Oxford.

Bheel, N., Benjeddou, O., Almujibah, H.R., Abbasi, S.A., Sohu, S., Ahmad, M., Sabri, M.M.S. 2023. Effect of calcined clay and marble dust powder as cementitious material on the mechanical properties and embodied carbon of high strength concrete by using RSM-based modelling. Heliyon, 9.

Bilgin, N., Yeprem, H.A., Arslan, S., Bilgin, A., Günay, E., Maroglu, M. 2012. Use of waste marble powder in brick industry. Construction and Building Materials, 29, 449–457.

Budhu, M. 2011. Soil mechanics and foundations. John Wiley & Sons.

Cui, S.L., Wang, J.D., Wang, X.D., Du, Y.F., Wang, X.P. 2018. Mechanical behavior and micro-structure of cement kiln dust-stabilized expensive soil. Arabian Journal of Geosciences, 11, 1–8.

Danish, A., Mosaberpanah, M.A., Salim, M.U., Fediuk, R., Rashid, M.F., Waqas, R.M. 2021. Reusing marble and granite dust as cement replacement in cementitious composites: A review on sustainability benefits and critical challenges. Journal of Building Engineering, 44.

Deboucha, S., Aissa Mamoune, S.M., Sail, Y., Ziani, H. 2020. Effects of ceramic waste, marble dust, and cement in pavement sub-base layer. Geotechnical and Geological Engineering, 38, 3331–3340.

Edora, A.B., Adajar, M.A.Q. 2021. Strength and permeability characteristics of expansive soil with gypsum and rice husk ash. International Journal of GEOMATE, 21, 28–34.

Fathonah, W., Intari, D.E., Mina, E., Kusuma, R.I., Mahfudoh. 2019. Stabilization of clay using slag and fly ash with reference to UCT value (Case study: Jalan kadusentar, pandeglang district-banten). IOP Conference Series: Materials Science and Engineering, 673.

Fathonah, W., Mina, E., Kusuma, R.I., Ihsan, D.Y. 2020. Stabilisasi tanah menggunakan semen slag serta pengaruhnya terhadap nilai California Bearing Ratio (CBR) (Studi Kasus: Jl. Munjul, Kp. Ciherang, Desa Pasir Tenjo, Kecamatan Sindang Resmi, Kabupaten Pandeglang). JurnalFondasi, 9, 87–93.

Hwang, E.H., Ko, Y.S., Jeon, J.K. 2008. Effect of polymer cement modifiers on mechanical and physical properties of polymer-modified mortar using recycled artificial marble waste fine aggregate. Journal of Industrial and Engineering Chemistry, 14, 265–271.

Jain, A.K., Jha, A.K. 2020. Geotechnical behaviour and micro-analyses of expansive soil amended with marble dust. Soils and Foundations, 60, 737–751.

Jain, A.K., Jha, A.K., Shivanshi. 2020. Geotechnical behaviour and micro-analyses of expansive soil amended with marble dust. Soils and Foundations, 60, 737–751.

Jalal, F.E., Mulk, S., Memon, S.A., Jamhiri, B., Naseem, A. 2021. Strength, hydraulic, and microstructural characteristics of expansive soils incorporating marble dust and rice husk ash. Advances in Civil Engineering, 2021.

Karaşahin, M., Terzi, S. 2007. Evaluation of marble waste dust in the mixture of asphaltic concrete. Construction and Building Materials, 21, 616–620.

Kumar, P., Harika, S. 2021. Stabilization of expansive subgrade soil by using fly ash. Materials Today: Proceedings 45, 6558–6562.

Kusuma, R.I., Mina, E., Fakhri, N. 2018. Stabilisasi tanah lempung lunak dengan memanfaatkan limbah gypsum dan pengaruhnya terhadap nilai California Bearing Ratio (CBR). Jurnal Fondasi, 7, 22–31.

Kusuma, R.I., Mina, E., Fathonah, W., Kartika, C.D. 2020. Stabilisasi tanah lempung organik menggunakan semen slag terhadap nilai cbr berdasarkan variasi kadar air optimum (Studi kasus jl. raya kubang laban, desa terate, kecamatan kramatwatu, kabupaten serang). Jurnal Fondasi, 9, 154.

Latifi, N., Vahedifard, F., Siddiqua, S., Horpibulsuk, S. 2018. Solidification–stabilization of heavy metal–contaminated clays using gypsum: Multiscale assessment. International Journal of Geomechanics, 18, 04018150.

Mina, E., Fathonah, W., Kusuma, R.I., Nurjanah, I.A. 2021. The utilization of lime and plastic sack fiber for the stabilization of clay and their effect on CBR value. Teknika: Jurnal Sains Dan Teknologi, 17, 289.

Mina, E., Kusuma, R.I. 2016. Pengaruh fly ash terhadap nilai CBR dan sifat-sifat propertis tanah studi kasus: Jalan Raya Bojonegara KM 19 Serang Banten. Fondasi: Jurnal Teknik Sipil, 5.

Minhas, A. 2016. Soil stabilization of alluvial soil by using marble powder. International Journal of Civil Engineering and Technology (IJCIET), 7, 7–12.

Murmu, A., Dhole, N., Patel, A. 2020. Stabilisation of black cotton soil for subgrade application using fly ash geopolymer. Road Materials and Pavement Design, 21, 867–885.

Muthu Kumar, M., Tamilarasan, V.S. 2015. Experimental study on expansive soil with marble powder. International Journal of Engineering Trends and Technology, 22, 504–507.

Nawaz, M., Heitor, A., Sivakumar, M. 2020. Geopolymers in construction-recent developments. Construction and Building Materials, 260, 120472.

Negi, A.S., Faizan, M., Siddharth, D.P. 2013. Soil stabilization using lime. International Journal of Innovative Research in Science, Engineering and Technology, 2, 448–453.

Nujid, M.M., Idrus, J., Azam, N.A., Tholibon, D.A., Jamaluddin, D. 2019. Correlation between California Bearing Ratio (CBR) with plasticity index of marine stabilizes soil with cockle shell powder. Journal of Physics: Conference Series, 1349.

Okagbue, C.O., Onyeobi, T.U.S. 1999. Potential of marble dust to stabilise red tropical soils for road construction. Engineering Geology, 53, 371–380.

Rashidi, M., Saghafi, M., Takhtfiroozeh, H. 2018. Genetic programming model for estimation of settlement in earth dams. International Journal of Geotechnical Engineering, 15, 887–896.

Rind, T.A., Karira, H., Mirani, S.A., Mari, A.K. 2020. Influence of ground granulated blast furnace slag on the index, compaction parameters and mechanical strength of khairpur mir's natural soil. Journal of Applied Engineering Sciences, 10, 83–88.

Saboya, F., Xavier, G.C., Alexandre, J. 2007. The use of the powder marble by-product to enhance the properties of brick ceramic. Construction and Building Materials, 21, 1950–1960.

Saygili, A. 2015. Use of waste marble dust for stabilization of clayey soil. Medziagotyra, 21, 601–606.

Setyono, E., Sunarto, Moro Gumilang, A. 2018. Pengaruh penggunaan bahan serbuk marmer pada stabilisasi tanah lempung ekspansif. Media Teknik Sipil, 16, 99–107.

Sinha, P., Iyer, K.K. 2020. Effect of stabilization on characteristics of subgrade soil: A review. Advances in Computer Methods and Geomechanics, 55, 667–682.

Uge, B.U. 2017. Performance, problems and remedial measures for roads constructed on expansive soil in

Ethiopia–A review. Civil and Environmental Research 9, 28–37.

Waheed, A., Arshid, M.U., Khalid, R.A., Gardezi, S.S.S. 2021. Soil improvement using waste marble dust for sustainable development. Civil Engineering Journal (Iran), 7, 1594–1607.

Wardana, I.G.N. 2009. Kelakuan tanah dengan sifat kembang-susut yang tinggi pada stabilisasi tanah dengan bahan serbuk marmer dan bahan stabilia. Jurnal Ilmiah Teknik Sipil, 13, 161–173.

Zada, U., Jamal, A., Iqbal, M., Eldin, S.M., Almoshaogeh, M., Bekkouche, S.R., Almuaythir, S. 2023. Recent advances in expansive soil stabilization using admixtures: Current challenges and opportunities. Case Studies in Construction Materials, e01985.