



Research Article

Strength properties of biopolymer treated clay/marble powder mixtures

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ABSTRACT

Depending on their unique layer structures and chemical structures, soil problems such as swelling, settlement and loss of strength can be seen especially on clay soils when exposed to water. Settlement occurring on clay soils on which the structure is built, causes various damages in the building. Additionally, in the clay soil interacting with water, strength loss occurs due to the effect of the building load. Today, when soil improvement techniques are developed and diversified, clay soils can be stabilized by using different additives. A clay soil that has been improved by adding waste marble powder within the scope of this study in certain percentages (5%, 15%, 25%), biopolymer added clay / marble powder samples were obtained by interacting with locust bean gum in certain percentages (0.5%, 1%, 1.5%). There are many studies in the literature on improving clay soils using only marble powder or only biopolymer. In this study, marble powder and biopolymer were used together and thus, the feasibility of a more effective soil improvement has been investigated. The results showed that the unconfined compressive strength of the biopolymer added clay-marble powder mixtures are higher when compared with natural clay. Similarly, shear box test results showed that the unconsolidated-undrained cohesions and internal friction angles of the doped clay samples increased. It was observed that the strength values of marble powder-added clay increased after improving with biopolymer.

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1. Introduction

Clayey soils are problematic soils because of the swelling and / or settlement behaviors. For eliminating this problems, clayey soils can be stabilize with additives. These additives can be industrial wastes such as marble powder, fly ash, silica fume and red mud (Çokça, 2001; Senol et al., 2006; Hossain and Mol, 2011; Edil et al., 2006; Yarbaşı et al., 2007; Brooks, 2009; İkizler et al., 2014). In addition to these, chemical additives and various polymers are also used in stabilization of clay soils (Tingle and Santoni, 2003; Akbulut et al., 2012; Akbulut et al., 2013).

Marble is a metamorphic rock formed by the metamorphism of limestone and dolomitic limestone. When marble blocks are cut to give a smooth geometric shape, high volumes of marble waste are produced (Hebhoub et

al., 2011). During the cutting process, water is used to prevent the cutting tip from overheating and dust generation. During the cutting of marbles, the mixture of water and marble powder comes out as a slurry. Turkey has approximately 5.2 billion cubic meters of marble reserves and, considering that about 30-40% of a marble block is generated as waste in the cutting process, it can be said that about 2.5 million tons of marble mud in marble production has emerged as waste in Turkey (Alyamaç and Aydın, 2015). The effects of waste marbles on the engineering and geotechnical properties of clay soils have been investigated in the literature (Gurbuz, 2015; Jain and Jha, 2020; Sivrikaya et al., 2020).

Biopolymers are organic polymers. Biopolymers are produced by biological organisms and easily found in nature (Ashraf et al., 2017). Soil improvement with using biopolymers is one of the soil improvement methods

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that do not harm the environment (Chang et al., 2019). The use of low ratios of biopolymer can increase the soil strength (Chang and Cho, 2019). There are many studies that use biopolymers to improve the strength properties of soils (Khatami and O'Kelly, 2013; Smitha and Sachan, 2016; Viswanath et al., 2017). In studies where biopolymers are used in soil improvement, usually xanthan gum (Lee et al., 2017; Lee et al., 2019; Singh and Das, 2020), guar gum (Ayeldeen et al., 2016; Latifi et al., 2016; Sujatha and Saisree, 2019) and gellan gum (Chang et al., 2016a; Im et al., 2017; Chang and Cho, 2019) are used. Swelling properties (Singh and Das, 2020) and permeability properties of soils (Wisniewski and Cabalar, 2014), can be improved with biopolymers. The geotechnical properties of clay soils can be improved with deep mixing using biopolymers (Arasan et al., 2017). In the production of nanoclay-composites, biopolymers are used to increase gel strength (Maier et al., 1993). Another biopolymer used in soil improvement is locust bean gum. It has been observed that the nanoclay-composites obtained by using locust bean gum have improved geotechnical properties when compared with natural clay (Kurt and Akbulut, 2014; Kurt and Akbulut, 2017; Majedi et al., 2019; Kurt Albayrak and Gencer, 2021). Locust bean gum is also called carob gum (Lopes da Silva et al., 1994). Locust bean gum has a non-ionic structure, and it is not affected by heat, pH and salt (Barak and Mudgil, 2014).

Within the scope of this study, marble powder which is a waste material and used in soil improvement, was added to a clay soil and, clay soils with marble powder were obtained. In the continuation of the study, marble powder-added clay soils were interacted with locust bean gum and, it has been investigated that how the biopolymer changes the strength properties of marble powder-added clay samples. There are many studies on improving clay soils using only marble powder or biopolymer. In this study, marble powder and biopolymer were used together and thus, the feasibility of a more effective soil improvement was investigated. For this purpose, a natural clay belonging to Erzurum Oltu region was mixed with marble powder in certain ratios obtained from Pazaryolu-Erzurum. Then, marble powder added clays were improved with locust bean gum in certain ratios and biopolymer added clay / marble powder samples were obtained. The experimental results of the samples obtained, were compared with the results of natural clay samples.

2. Materials and Method

2.1. Clay

The clay (C) sample from Erzurum (Oltu-Narman) environment was used in this study. The clay content of natural clay (<0.002 mm) is 42% and its specific gravity is 2.64. In the classification made according to the Unified Soil Classification System (USCS), it was seen that, it is CH (high plasticity clay). Some geotechnical properties of natural clay are given in Table 1 and the results of X-ray fluorescence spectrometry (XRF) analysis of the clay sample, are given in Table 2.

Table 1. Clay properties.

Properties	Clay
Liquid limit, %	70
Plastic limit, %	27
Plasticity index, %	43
Optimum moisture content, %	26
Maximum dry unit weight, kN/m ³	15.2

Table 2. Chemical compounds of clay and marble.

Content	Clay, %	Marble, %
SiO ₂	59.3	2.5
Al ₂ O ₃	16.5	0.4
CaO	1.50	54.0
Fe ₂ O ₃	8.0	0.3
K ₂ O	1.6	<0.1
MgO	2.1	0.5
MnO	<0.1	<0.1
Na ₂ O	1.4	0.1
P ₂ O ₅	0.2	<0.1
TiO ₂	0.6	<0.1
LOI	8.5	42.05

2.2. Marble powder

Waste marble powder (M) used in the experiments was obtained from Erzurum's Pazaryolu district. In the experiments, marble powder was used by sieving it through a No. 40 sieve (sieve diameter: 0.425 mm). The specific gravity of the marble powder was 2.85. XRF analysis results of the marble powder, are shown in Table 2.

2.3. Biopolymer (locust bean gum)

The chemical content of the locust bean gum (L) is a type of hydrocolloids, Galactomannan, its pH is between 5-7, and its viscosity is between 2000-3500 cps (Kurt and Akbulut, 2014; Kurt Albayrak and Gencer, 2021). Locust bean gum, is a biopolymer and obtained from the carob tree (*Ceratonia siliqua*) of legume group, has a thickener, gelling and stabilizing properties (Dey et al., 2012).

2.4. Specimen preparation

Marble powder-added clay samples were derived by mixing clay with certain percentages of marble powder (5%, 15%, 25%) in dry form. While obtaining samples with biopolymer additives, locust bean gum was mixed with distilled water in a mechanical stirrer until dissolved at 1000 rpm and, by calculating the percentage of water used in the experiments (0.5%, 1%, 1.5%), clay and marble powder-added clay samples were added together with water. The samples prepared, are shown in Table 3.

Table 3. Samples.

Sample	Clay	Marble powder	Locust bean gum
C-%0 L	100	-	-
C-%0.5L	100	-	0.5
C-%1L	100	-	1
C-%1.5L	100	-	1.5
C-%5M-%0L	95	5	-
C-%5M-%0.5L	95	5	0.5
C-%5M-%1L	95	5	1
C-%5M-%1.5L	95	5	1.5
C-%15M-%0L	85	15	-
C-%15M-%0.5L	85	15	0.5
C-%15M-%1L	85	15	1
C-%15M-%1.5L	85	15	1.5
C-%25M-%0L	75	25	-
C-%25M-%0.5L	75	25	0.5
C-%25M-%1L	75	25	1
C-%25M-%1.5L	75	25	1.5

2.5. Tests

Direct shear box and unconfined compressive strength tests were carried out on clay samples, marble powder added clay samples and biopolymer added samples obtained by improving them with locust bean gum. Unconfined compression tests were performed on the basis of ASTM D 2166. The unconfined compression tests were conducted on the cylindrical samples (diameter is 35mm, height is 70 mm) compacted at optimum moisture content at standard proctor energy. The optimum moisture content and maximum dry unit weight values of the samples determined by the standard proctor test are, shown in Table 4 (Kurt Albayrak and Altun, 2018).

Direct shear box tests were carried out according to ASTM D 3080. Shear box experiments were carried out on samples placed in 6 cm diameter shear box from compaction samples prepared by optimum moisture content.

3. Results and Discussion

3.1. Unconfined compression test results

The unconfined compressive strengths obtained as a result of the unconfined compression test carried out, are given in Table 5. The change in the unconfined compressive strength of the samples with the increase in the ratio of locust bean gum, is seen in Fig. 1.

When Fig. 1 is examined, it is observed that when the locust bean gum percentage is increased, the unconfined compressive strength of clay and marble powder added clay also increases. According to Fig. 1, the unconfined compressive strength of clay, increased by 46%, 54% and 136%, when the biopolymer percentage is 0.5%, 1%, 1.5% respectively. Due to the fact that biopolymers can

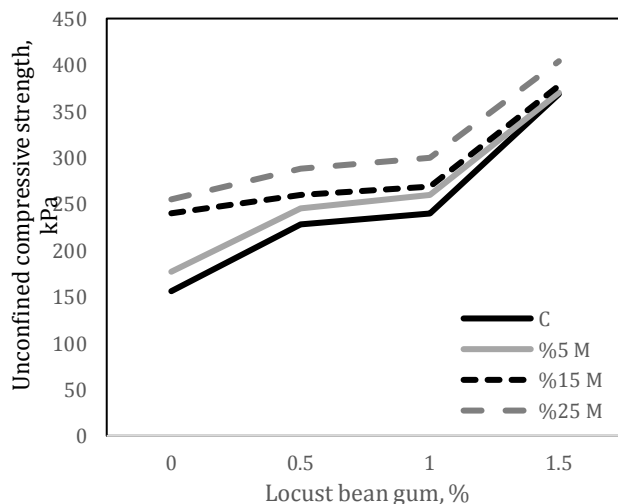
interact effectively with fine grained soils, it can be thought that the unconfined compression strength increases with the increase in the percentage of locust bean gum (Chang et al., 2015). Biopolymer-soil matrices with high strength are formed, with the ability of biopolymers that can interact with fine-grained soils due to their large electrically charged surface area (Chang et al., 2016b). Chen et al. (2013) similarly stated that, bond structures are formed between biopolymer and soil particles and, this increased the strength.

Table 4. Compaction parameters of samples.

Sample	Optimum moisture content, %	Maximum dry unit weight, kN/m ³
C-%0 L	26	15.2
C-%0.5L	23	14.4
C-%1L	22.5	14.3
C-%1.5L	22	14.7
C-%5M-%0L	23.9	15.2
C-%5M-%0.5L	19.5	14.8
C-%5M-%1L	22.5	14.7
C-%5M-%1.5L	19	15.3
C-%15M-%0L	22.2	15.3
C-%15M-%0.5L	22	15.1
C-%15M-%1L	24	15.1
C-%15M-%1.5L	19.5	15.5
C-%25M-%0L	23	15.4
C-%25M-%0.5L	19.5	15.4
C-%25M-%1L	21.4	15.4
C-%25M-%1.5L	18	15.7

Table 5. Unconfined compression test results of samples.

Sample	Unconfined compressive strength, kPa
C-%0 L	156
C-%0.5L	228
C-%1L	240
C-%1.5L	369
C-%5M-%0L	177
C-%5M-%0.5L	245
C-%5M-%1L	260
C-%5M-%1.5L	370
C-%15M-%0L	240
C-%15M-%0.5L	260
C-%15M-%1L	269
C-%15M-%1.5L	378
C-%25M-%0L	255
C-%25M-%0.5L	288
C-%25M-%1L	300
C-%25M-%1.5L	404

**Fig. 1.** Change in unconfined compressive strength with locust bean gum.

By comparing the unconfined compression strength of the samples obtained by adding locust bean gum solution to clay samples with 5% marble powder added with the unconfined compressive strength of natural clay, the biopolymer percentage increased by 57%, 67% and 137% for 0.5%, 1%, 1.5%, respectively. By comparing the unconfined compression strength of the samples obtained by adding locust bean gum solution to 15% marble powder added clay samples with the unconfined compression strength of natural clay, the biopolymer percentage increased by 67%, 72% and 142% for 0.5%, 1%, 1.5%, respectively. By comparing unconfined compression strength of the samples obtained by adding locust bean gum solution to 25% marble powder added clay samples with the unconfined compression strength of natural clay, the biopolymer percentage increased by 85%, 92% and 159% for 0.5%, 1%, 1.5%, respectively.

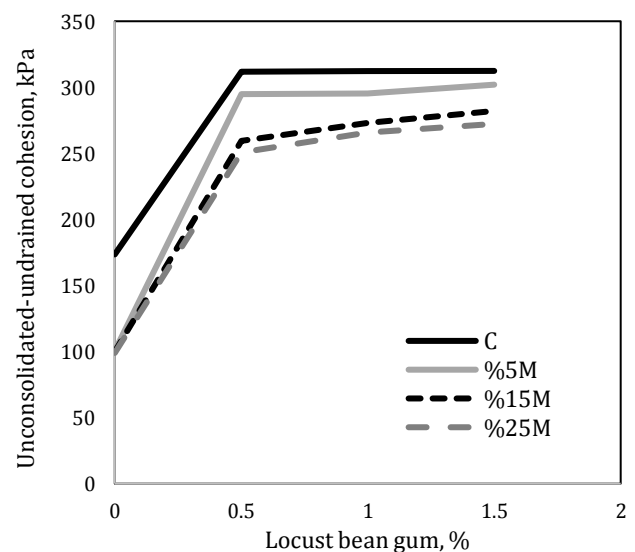
In addition, the increase in marble additive, generally increased the unconfined compression strength of biopolymer added clay samples. It is seen that locust bean gum additive increases the unconfined compression strength of natural clay and marble powder added clay samples.

3.2. Direct shear box tests

The experimental results obtained as a result of the direct shear box tests performed are given in Table 6. The change in unconsolidated-undrained cohesion and internal friction angle with the increase in locust bean gum percentage, is given in Figs. 2 and 3, respectively.

Table 6. The direct shear box test results of samples

Sample	Unconsolidated undrained cohesion, kPa	Internal friction angle, °
C-%0 L	174	7.7
C-%0.5L	312	7.9
C-%1L	312	8.0
C-%1.5L	312	9.5
C-%5M-%0L	101	7.9
C-%5M-%0.5L	295	8.0
C-%5M-%1L	296	8.2
C-%5M-%1.5L	302	10.4
C-%15M-%0L	100	12.4
C-%15M-%0.5L	260	12.8
C-%15M-%1L	273	17.0
C-%15M-%1.5L	282	18.0
C-%25M-%0L	99	13.0
C-%25M-%0.5L	251	15.0
C-%25M-%1L	266	18.2
C-%25M-%1.5L	272	18.4

**Fig. 2.** Change in unconsolidated-undrained cohesion values of samples.

When Fig. 2 is examined, it is observed that as the percentage of marble increases, unconsolidated-undrained cohesion of natural clay decreases. The cohesion values of 0.5%, 1%, 1.5% locust bean gum added 5% marble powder/clay samples increased by 70%, 70.3% and 74% respectively according to the cohesion values of natural clay. The cohesion values of 0.5%, 1%, 1.5% locust bean gum added 15% marble powder/clay samples increased by 50%, 57% and 62% respectively according to the cohesion values of natural clay. Similarly, the cohesion values of 0.5%, 1%, 1.5% locust bean gum added 25% marble powder/clay samples increased by 44%, 53% and 56% respectively according to the cohesion values of natural clay.

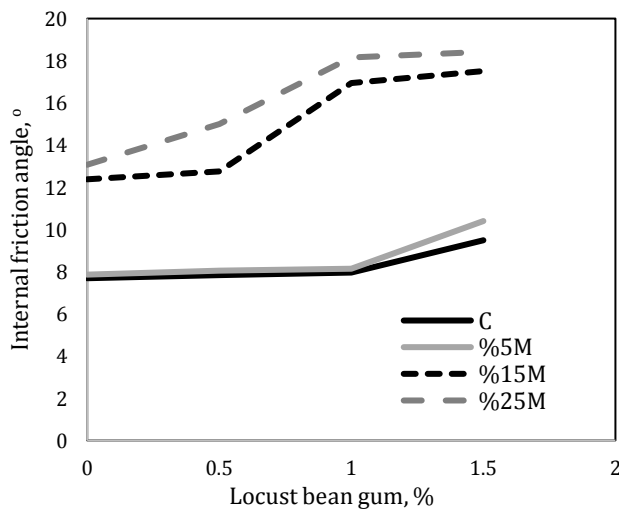


Fig. 3. Change in internal friction angle values of samples.

According to Fig. 3, as the percentage of marble powder increased, the internal friction angle of natural clay increased partially. In addition, it is seen that the value of the internal friction angle of natural clay increased by 2%, 3.5%, 23.4% respectively for the locust bean gum percentage of 0.5%, 1%, 1.5%.

The internal friction angle values of natural clay increased by 4.5%, 6% and 35%, when compared with the internal friction angle values of the 0.5%, 1%, 1.5% locust bean gum solution added 5% marble powder/clay samples, respectively. According to the internal friction angle values of natural clay of the internal friction angle values of the samples obtained by adding 0.5%, 1%, 1.5% locust bean gum solution to 15% marble powder/clay samples, increased by 66%, 120%, 128% respectively. According to the internal friction angle values of natural clay of the internal friction angle values of the samples obtained by adding 0.5%, 1%, 1.5% locust bean gum solution to 25% marble powder/clay samples, increased by 95%, 136%, and 140% respectively.

It is seen that the biopolymer additive generally increases the internal friction angle and cohesion. The direct shear box test results showed that the biopolymer additive increased the cohesion in natural clay, while the increase in the biopolymer percentage did not change the cohesion significantly. The internal friction angle increased with the increase in the biopolymer percentage.

Significant increases in both cohesion and internal friction angle occurred with the increase in the ratio of biopolymer in marble powder added clays.

The change in internal friction angle and cohesion, changes according to the soil type, grain diameter and type of biopolymer (Soldo et al., 2020). Due to the increased contact between particles in biopolymer treated soils, it is thought that the internal friction angle will increase (Chang et al., 2016b). Soldo and Miletic (2019) stated in their study that the biopolymer of xanthan gum significantly increased the cohesion in cohesionless soils but, they did not change the internal friction angle significantly. They pointed out that this change, is the interaction between the biopolymer and the soil related to the grain size. They stated that the biopolymer forms bonds between distant particles by coating the coarse grains and, that the electrostatic bond occurs with fine-grained soils and that this bond is stronger. It is believed that the strengthening mechanism of biopolymers is the formation of biopolymer-clay soil matrices and the improvement in friction through coarse grains (Chang et al., 2016b). In this study, it can be thought that the increase in the locust bean gum ratio and the increase in the cohesions and internal friction angles of the marble powder-added clays can be result from the formation of biopolymer-clay matrices. Additionally, the increase in friction caused by marble powder could increase the internal friction angle of locust bean gum added samples.

4. Conclusions

Within the scope of the study, the strength properties of the samples obtained as a result of improving the marble powder-added clay samples with the locust bean gum were investigated. For that purpose, a clay belonging to Erzurum-Oltu region was firstly mixed with marble powder obtained from Erzurum-Pazaryolu at certain ratios and as a result, clay with marble powder was obtained. Then, marble powder added clays were treated with locust bean gum in certain ratios and as a result, locust bean gum added clay/marble powder samples were obtained. Direct shear box and unconfined compressive strength tests were performed on the samples. The results obtained, are listed below.

- Unconfined compressive strength of marble powder-added clay samples increased with the increase in the percentage of marble powder.
- As the locust bean gum percentage increased, the unconfined compressive strength of natural clay increased.
- The unconfined compressive strength of locust bean gum added clay / marble powder mixtures increased with locust bean gum percentage.
- The unconsolidated-undrained cohesion values of natural clay samples with added marble powder decreased with the marble powder percentage.
- The internal friction angle of clay increased with marble powder.

- As the locust bean gum percentage increased, the unconsolidated-undrained cohesion value of clay increased.
- With the increase in the percentage of locust bean gum, the internal friction angle of natural clay also increased.
- The unconsolidated-undrained cohesion values of the locust bean gum added clay / marble powder mixtures increased with locust bean gum percentage.
- With the increase in the percentage of locust bean gum, the internal friction angle of the clay/ marble powder samples also increased.

It is known that marble powder is used in the clay soils stabilization. It is clear that the addition of marble powder increases the strength of clay. Additionally, higher strength values were obtained by adding locust bean gum to natural clay as well as marble powder. As a result of the study, it has been shown that the use of an environmentally friendly polymer, locust bean gum together with marble powder which is a waste material, provides a more effective stabilization in the stabilization of clay soils. Additionally, it is thought that with the stabilization of clay soils with marble powder and biopolymer, the damages that may occur due to the foundation soil in the structures to be built on clay soils will be prevented. It is known that other properties such as hydraulic conductivity and swelling pressure change with the change in the strength properties of clays, and in order to better understand the effects of biopolymers on the geotechnical properties of marble powder added clays in the future studies, it is thought that the changes in the internal structure of the samples should also be examined with special analysis methods besides some properties such as swelling pressure, hydraulic conductivity. In addition, due to the degradation of biopolymers over time, their long-term performance should be studied in detail.

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