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Research

The Effect of the Difference in Stone Ratios of Ca-Bentonite Produced Under The Same License On Swelling

SAVAŞ KOÇ[1*]

Bentaş Bentonit, Fatsa Osb. 101. Sokak No:20 Fatsa/ORDU, savas_koc1991@hotmail.com, Orcid: 0009-0006-3614-9458

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* Corresponding author

ABSTRACT

In this study, the effect of stone ratios of bentonite mines in different locations on swelling capacities was investigated. Bentonite is a type of clay that has a high swelling capacity and contains various clay minerals, especially montmorillonite. The swelling capacity directly depends on the amount of these activated clay minerals and the proportion of stones. In bentonites with a high stone content, as the proportion of non-clay materials (quartz, feldspar, etc.) increases, the swelling capacity decreases. Bentonites with high proportions of these stones do not absorb water, reduce the active surface area of bentonite and limit its swelling capacity. Since bentonites in different locations vary according to their formation processes and mineralogical composition, even mines with the same stone ratio can have different water holding capacity. In this context, there is an inversely proportional relationship between stone ratio and swelling capacity; However, it was concluded that this relationship was also affected by factors such as mineralogical structure, montmorillonite percentage and grain size distribution.

1. Introduction

Bentonite is a type of clay that is formed from the alteration of volcanic ash and is characterized by its high-water retention capacity [1]. It predominantly consists of the mineral montmorillonite. Bentonites are typically found in white, gray, or green colors and exhibit swelling properties when in contact with water. This swelling ability makes bentonite a valuable material for various industrial and environmental applications[8].

Historically, bentonite has been used for various purposes since ancient times. [24]. Initially utilized in ceramics and as an adhesive, it has evolved to become an essential material in construction, agriculture, environmental engineering, and many other fields. The water retention capacity of bentonite makes it indispensable in soil improvement and waterproofing applications. Additionally, bentonite plays an active role in various chemical and physical processes due to its high surface area and ion exchange capacity.

The physical and chemical properties of bentonite are critical factors that determine its usability across different applications [7]. These properties can vary significantly due to various geological and mineralogical factors. This study will examine the stone content, swelling capacity, and bentonite structures from different locations, while also addressing the physical and chemical properties of bentonite [1]

Figure 1. Bentonit

Bentonite, a type of clay formed from the alteration of volcanic ash, has a history that dates back to ancient civilizations. Evidence suggests its use around 4000 B.C. in Mesopotamia, where it was employed for water

purification and as a construction material [10]. Ancient Egyptians also utilized bentonite in mummification processes and pottery production [11]. The discovery of significant bentonite deposits in the United States during the 19th century accelerated its industrial applications. Named after Fort Benton in Wyoming, bentonite became critical in mining, drilling, and foundry industries [12].
In the 20th century, the use of bentonite expanded into military applications and agriculture, where it was observed to enhance water retention in agricultural lands [13]. Today, bentonite is widely used in environmental engineering, particularly in waste management systems, as well as in the cosmetic industry. The historical significance of bentonite underscores its versatility and its essential role throughout human history [14].

2. Geological structure of bentonite

2.1. Mineral Composition

Main Mineral: Bentonite primarily consists of montmorillonite, a clay mineral that has a significant swelling capacity when it comes into contact with water [6].
Other Minerals: Bentonite may also contain kaolinite, illite, quartz, feldspar, and various other minerals. These minerals are important factors that influence the properties of bentonite [18].

Table 1. Physical and Chemical Properties of Bentonite

Property	Description
Chemical Formula	Generally $(Na,Ca)_{0.33}(Al,Mg)_2Si_4O_{10}(OH)_2 \cdot nH_2O$
Mineral Group	Smectite group clay mineral
Crystal Structure	Layered (2:1 type; two silica tetrahedral + one alumina octahedral sheet)
Color	White, gray, cream greenish or brown
Density	~2.6 g/cm³
Specific Gravity	2.2 – 2.8
Moisture Retention	High (absorbs and retains water)
Swelling Capacity	Very high for sodium bentonite
Surface Area	600–800 m²/g (very high)
Cation Exchange Capacity	70–100 meq/100g
Hardness	1 – 2
Plasticity	High; forms gels with water
Solubility	Insoluble in water, but swells and forms suspension
Main Elements	Si, Al, Mg, Na, Ca, Fe

2.2. Formation Process

Volcanic Origin: Bentonite typically forms from tuff and volcanic ash resulting from volcanic eruptions, which are subjected to climatic and chemical influences over time. This process begins with the interaction of volcanic glass and minerals with water and other chemicals.

Chemical Alteration: Volcanic materials, especially those containing silica and aluminum, interact with water to transform into clay minerals such as montmorillonite. This process occurs through natural interactions over many years [15].

2.3. Geological structure and layering

Layered Structure: Bentonite deposits generally exhibit a layered structure. These layers may show different mineral compositions and physical properties.
Thickness and Density: The thickness and density of bentonite deposits can vary depending on local geological conditions. Deposits can range from a few centimeters to several meters in thickness [5].

2.4. Physical properties

Water Absorption Capacity: Bentonite can swell significantly when it comes into contact with water. This property makes bentonite useful in construction and engineering applications.
Plasticity and Flow Properties: Bentonite exhibits plastic characteristics, offering advantages in workability. This makes it a preferred material in various industrial applications [9].

2.5. Distribution and applications

Geological Distribution: Bentonite can be found in many regions worldwide. Notable areas include the United States, Türkiye (especially in the Ordu, Kütahya, and Eskişehir regions), and some European countries [16].
Industrial Uses: Bentonite is used in various fields, including construction, geotechnical engineering, water proofing, food industry, and environmental engineering [17].

3. Physical and chemical properties of bentonites

The physical and chemical properties of bentonite are fundamental characteristics that make it applicable in many industries.

3.1. Physical properties:

- Color: Bentonites can be found in colors such as white, gray, green, or brown, depending on their mineral composition.
Density: The density of bentonite typically ranges from 2.0 to 2.5 g/cm³.
Swelling Capacity: Bentonites exhibit significant swelling capacity when in contact with water, which enhances their water retention capabilities.

Granule Size: Bentonites generally have granule sizes of 75 microns or smaller, facilitating their interaction with water.
Surface Area: Bentonites possess a high surface area (typically 600-800 m^2/g), making them ideal for adsorption and ion exchange applications.

3.2. Chemical properties:

Mineral Composition: Bentonites primarily consist of montmorillonite, but they may also contain other mineral components such as quartz, feldspar, and zeolites.
Ph Value: The pH value of bentonite typically ranges from 7 to 9, making it a neutral material.
Ion Exchange Capacity: Bentonites have a high ion exchange capacity (usually 50-100 meq/100g), allowing them to participate in various chemical reactions.
Water Retention Capacity: Bentonites can retain 3 to 10 times their weight in water. This property makes them valuable in agricultural and environmental engineering applications.

4. Stone ratio

Stone content refers to the proportion of non-clay materials (such as quartz, topaz, opal, tuff, zeolites, perlite, etc.) in bentonite mineral deposits. These non-clay minerals do not absorb water and reduce the active surface area of bentonite. The stone content has a direct impact on the water retention capacity of bentonite. High stone content can reduce the swelling capacity of bentonite by limiting its water absorption.

4.1. Impact of Stone Content on Swelling Capacity:

High Stone Content: When the stone content is high (above 30%), the effectiveness of bentonite in applications requiring swelling and water retention diminishes. This is because the non-clay minerals take up space that would otherwise be occupied by montmorillonite, which is responsible for the swelling properties.

4.2. Low Stone Content: Conversely, a lower stone content (below 20%) generally indicates a higher quality bentonite with better swelling capabilities. This type of bentonite is more effective in applications such as waterproofing, drilling fluids, and soil stabilization.

4.3. Applications: In construction and environmental applications, bentonites with lower stone content are preferred due to their superior performance in retaining water and providing effective sealing against fluid movement.

5. Bentonit Structures

Stone ratios in bentonite mines in different locations vary depending on the geological, mineralogical and environmental factors in that region. Bentonite is a type of clay formed as a result of the alteration of volcanic tuffs, and the degree of this transformation directly affects the stone ratio. In regions where the alteration process is intense and complete, volcanic materials are largely transformed into clay minerals such as montmorillonite, while when the process is incomplete, non-clay materials (stone, glass particles, feldspar, quartz, etc.) are preserved in the tuff and the stone ratio increases. In addition, the main type of volcanic rock in which bentonite is formed also affects this ratio; bentonites of rhyolitic origin are generally purer and have a lower stone ratio, while bentonites formed as a result of alteration of andesitic or basaltic tuffs have a higher proportion of stones. The depositional environment is also an important factor; bentonites deposited in marine or lake environments may be more homogeneous and have low stone content, while heterogeneity and stone content may increase in bentonites formed in terrestrial environments. In addition, tectonic movements, fault zones or materials that are mixed into the bed later by surface effects in the region can also increase the proportion of stone. For this reason, the proportion of stone in bentonite mines in different locations varies depending not only on the source of the raw material, but also on environmental and geodynamic conditions. [2]

The stone content in bentonite deposits varies based on geological, mineralogical, and environmental factors in different regions. Bentonites are formed from the alteration of volcanic tuffs, and this transformation process affects their mineralogical composition and physical properties.

Türkiye bentonite reserves are approximately 240 million tons. Ground bentonite production in Turkey has increased steadily over the past two decades. Known bentonite deposits in Turkey are located in Edirne/Enez, Çankırı, Çanakkale, Kütahya-Demirli, Manisa-Osmançalı, Tokat-Reşadiye, Ankara-Kalecik, Ordu-Ünye-Fatsa, and Giresun-Tirebolu [23].

USA: Wyoming is known as the largest bentonite producer globally. The bentonite deposits here are characterized by high montmorillonite content, with stone contents generally ranging from 10% to 20%.

China: China is a significant player in bentonite production, particularly in the Inner Mongolia region, where high-quality bentonites are available. The stone content in these deposits varies between 15% and 25%.

Other Countries: Countries like Argentina, Mexico, and Spain also have notable bentonite deposits. The properties of bentonites in these regions vary based on local geological conditions.

6. Swelling capacity

Bentonite, especially in the form of sodium bentonite, has an exceptional swelling capacity. This feature is due to the mineral montmorillonite in the structure of bentonite.

One of the most distinctive properties of clays is their volume change due to water adsorption. In this respect, clay minerals are classified as swelling (smectite) and non-swelling (mica). Naturally swelling clay minerals contain hydrated cations such as Na^+ and Li^+. Smectites swell even with the adsorption of atmospheric moisture. Non-swelling clay minerals generally contain non-hydrated K+ and divalent cations as interlayer cations. The swelling properties of clay minerals depend on the type and number of exchangeable cations[21]. Some clays or clay minerals are known to swell completely, some swell slightly, and some swell significantly. In particular, the swelling and dispersion of smectites and the bentonites that comprise them as the primary clay minerals are closely related to the type and amount of cations between the 2:1 layers [22].

The amount of montmorillonite mineral in bentonite samples is the primary determinant of swelling capacity. Bentonites with a higher montmorillonite content have a higher swelling capacity. The stone minerals, such as quartz and feldspar, present in bentonite samples, however, reduce the montmorillonite ratio. These stone minerals fill the voids between the montmorillonite crystals, thereby decreasing the water absorption and swelling capacity[20].

Furthermore, the stone fragments alter the crystal structure and inter-crystalline spaces of the montmorillonite. They disrupt the orderly structure of the montmorillonite crystals, which in turn reduces the water absorption and swelling capacity. The stone minerals also modify the pore structure and pore size distribution of the bentonite samples. A higher stone content results in a structure with fewer and smaller pores, limiting the water absorption and swelling capacity.

Additionally, the stone minerals decrease the total surface area of the bentonite samples. The reduced surface area diminishes the adsorption of water molecules and, consequently, the swelling capacity. In summary, as the stone content in bentonite samples increases, the montmorillonite ratio decreases, and the crystal structure, pore structure, and surface area are adversely affected. These changes collectively lead to a reduction in the water absorption and swelling capacity of the bentonite.

6.1. Swelling capacity test of the samples taken

In this study, 3 different samples were taken from bentonite mines in different locations in Ordu province and named as OrFa-1, OrFa-2 and OrFa-3. The samples taken are dried and sieved through a 75-micron sieve (no: 200 sieve). The sample to be used is usually taken as 2 gr. 2 g of sample is placed in the tape measure, 100 ml of pure water is added to it. The sample is left to swell freely in water. The prepared sample is not subjected to any mixing process. It is waited for about 24 hours in a constant environment at room temperature. At the end of 24 hours, the volume reached by the swelling of the bentonite is read directly from the tape measure. The measured volume is expressed in ml/2g. Table 2. The capacity index is evaluated according to the quality interpretation. The three different samples we took from our study were tested in order and the results are available in the table below. [3]

Figure 2. Swelling capacity test of the sample taken

Table 2. Inflatable capacity quality review [4]

Swelling Index (mL/2g)	Quality Review
20 and above	Very good quality
15-20	Good quality
10-15	Medium quality
5-10	Low quality
<5	Not suitable

Table 3. Evaluation of the samples taken

Examples	Stone ratio	Swelling capacity	Quality review
OrFa-1	%27	10,3 ml/2g	Medium quality
OrFa-2	%25	14,0 ml/2g	Medium quality
OrFa-3	%31	7,5 ml/2g	Low quality

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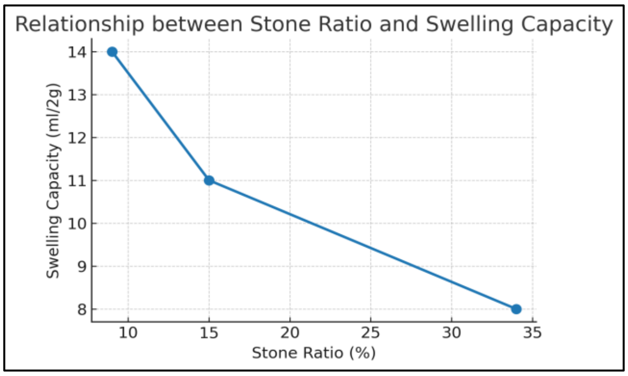

Figure 2. Relationship between stone ratio and swelling capacity

6.2. Applications of Bentonite's Swelling Capacity

The swelling capacity of bentonite plays a crucial role in many industrial and environmental applications:
Construction Engineering: Bentonites are used in foundational construction applications. They provide

waterproofing in foundation excavations and soil stabilization.
Environmental Applications: Bentonites are employed to ensure water impermeability in waste disposal sites, playing a critical role in preventing environmental pollution[17].
Oil and Gas Industry: Bentonites are used as drilling fluids. They help control the flow of water and other liquids during drilling operations.
Agriculture: Bentonites are used as soil conditioners, enhancing the water retention capacity of soil and supporting plant growth.
Cat Litter: Bentonites are widely used in cat litter. Their swelling properties help absorb liquids and prevent unpleasant odors[19].

7. Conclusion

The OrFa-1 example was considered as a medium-quality material with a low stone ratio (27%) and 10,3 ml/2g swelling capacity. This example shows that the swelling capacity is still good and the water absorption capacity is sufficient because the stone ratio is low. Therefore, it is located in the middle quality class.
In the case of OrFa-2, the ratio of the stone was slightly higher (25%), which led to the swelling capacity to 14 ml/2g levels. However, this value can still be considered medium. Although the increase in the ratio of the stone limits the swelling capacity of the clay, it can still be stated that the water retention capacity of the clay is at the moderate quality level.
OrFa-3 sample has a much higher stone ratio (31%). This high stone ratio has led to the swelling capacity of the clay to 7, 5 ml/2g. This decrease in swelling capacity caused the material to be evaluated as low quality. The high stone ratio has seriously reduced the water absorption capacity of the material and thus affected quality negatively.
The ratio of stone is one of the largest factors affecting swelling capacity. However, the content of the mine is calcium or sodium, the proportion of the minerals it contains, the types of stones it contains, and many more active inflatable capacities affect and block quality. With a low stone ratio, a higher swelling capacity can be achieved, which improves quality by increasing the water retention capacity of the material.
Which improves quality by increasing the water retention capacity of the material.
These findings highlight that the swelling capacity of bentonite, used in geotechnical engineering, construction projects, cat sand production, and other applications, is a key quality indicator for material selection. In addition, it should be noted that materials containing high stone ratio will be limited to water retention and swelling capacities.

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