The International Journal of Energy & Engineering Sciences, 2023, 8 (1) 1-8
ISSN: 2602-294X - Gaziantep University

THE CHANGE OF COMPRESSIVE STRENGTH OF CONCRETE WITH BENTONITE CLAY MINERALS

Ebru Gedik[1], Adem Atmaca[2*]

[1] Department of Civil Engineering, Gaziantep University

[2] Department of Mechanical Engineering Gaziantep University

[*] Corresponding author, aatmaca@gantep.edu.tr, +90 342 360 1200 (3999)

ABSTRACT

This study includes a series of experimental studies to investigate the use of bentonite clay minerals obtained from Malatya region instead of some of the cement in concrete production and thus the effect of the samples produced by reducing the use of cement on the 7- and 28-days compressive strength. For this purpose; %0, %5, %15, %30 bentonite clay was replaced by Portland cement CEM II 42.5 R by volume in proportions and standard mortar samples were prepared in 5 different series, including control samples. Workability of fresh concrete was determined by slump test and flow-table test. Compressive strength tests were performed on 7 and 28 days on the 100x100x100 mm hardened cube concrete samples. As a result of the mechanical tests of the samples, it was determined that the strength increase of the B5 sample at 7 days compared to the control sample was 146% higher, at 28-days was 94.7% higher strength values. The best strength value was determined in the B5 series and it was observed that 5% bentonite substitute has a good effect on compressive strength.

Keywords: Bentonite, Cement, Concrete, Mechanical Strength

1. INTRODUCTION

Bentonite a soft colloidal aluminum hydro silicate with 85% montmorillonite as its main mineral, is a clay mineral with a large surface area that swells when in contact with water [1]. Bentonite is named after the region where it is found and was first discovered by Knight in 1898 near Ford-Benton, USA. This clay mineral was named "Montmorillonite" because another clay with the same property was later found in the Montmorillon region of France [2]. Bentonite can be in various colors such as white, gray, green, yellow, pink, purple and red. In addition to this, mica, feldspar, pyrite, quartz, gypsum and some other minerals can also be found in its structure [3, 4]. The specific gravity of dry bentonite varies between 2.5 and 2.8 gr/cm^3, depending on its quality and origin. In similar products that are pulverized, it decreases to a noticeable extent and shows the level of 1.6-1.8 gr/cm^3 [5].

Our country has an important bentonite potential due to its diverse geological structure and there are large bentonite deposits with different characteristics in Türkiye. Türkiye's important bentonite deposits are located in Edirne, Ankara, Eskisehir, Canakkale, Kutahya, Balıkesir, Cankiri, Konya, Corum, Tokat and Ordu provinces. Among these deposits, the reserves in Ankara and Tokat are drilling mud industry, the reserves in Cankiri, Corum and Canakkale are foundry industry; the reserves in Edirne, Ordu, Balıkesir, Kutahya and Eskisehir are qualified bentonites suitable for bleaching paper and detergents and oils [6]. On the other hand, Malatya-Elazıg territory also has large bentonite reserves in places and can be used for pelleting after two beds are activated with soda. Trabzon (Arsin), Giresun (Tirebolu) in the Eastern Black Sea region; bentonite deposits are known to exist in the Konya regions of Central Anatolia [7, 18].

The easily accessible and abundant presence of bentonite clay minerals has brought wide areas of use in the industry. The usage areas of bentonite; as a shortening agent for setting time in gypsum, as a binding material in the manufacture of molds in the casting industry, as an additive in ceramics and to increase the strength of the material. It is also used in the construction sector for soil improvement works and to provide impermeability [19]. In addition, it is used as a catalyst material in fire extinguishing systems, various liquid foods, paint industry sectors and many chemical industries [8].

In this study, bentonite clay, which is extracted from Malatya region was used as mineral additive and laboratory experiments of mixtures with bentonite additives in different substitute amounts were carried out. The aim of this study is to examine the effects of bentonite clay minerals on the mechanical properties of concrete for reducing the amount of cement use [14-17]. The main objectives are evaluate the mechanical effects of bentonite content on concrete mortars and determine the compressive strength of bentonite-containing mortars with the concern of durability. In addition, it is aimed to conduct experimental studies to acquire new types of concrete with relatively better mechanical properties.

2. MATERIALS AND METHOD

In this study, in order to reduce the amount of cement usage, the usability of bentonite clay as a minerals additive in concrete and its effect on concrete mechanical properties were tried to interpret.

2.1. Materials

Oven-dry natural coarse aggregates were preferred in the production of concrete and the maximum grain size of these aggregates were 10 mm. The coarse aggregate used in this experimental study was obtained from Gaziantep-Center; aggregates are less angular-round, had high sphericity and low surface roughness. The water absorption capacity and specific gravity of the aggregates were determined according to TS EN 1097-6 [9], and are presented in Table 1.

Table 1. Properties of coarse aggregates

Types of Aggregates	Sieve size (mm)	SSD Bulk Density (g/cm^{3})	Specific Gravity (g/cm^3)	Absorption Capacity (%)
Gravel	4-10	0.874	2.525	3.0

The artificial aggregates were produced in the Gaziantep University Construction Laboratory environment; it has a round-spherical shape and the surface roughness is quite low. Artificial aggregates were produced in a tilted pan by cold bonded agglomeration process of a powder mixture consisting of 90% ground granulated blast furnace slag and 10% portland cement by weight. The percentage content, water absorption capacity and specific gravity of the artificial aggregate used in the study are given in Table 2.

Table 2. Properties of artificial aggregates (10% cement 90% slag)

Types of Aggregates	Sieve size (mm)	Appearent Specific Gravity (g/cm^{3})	Specific Gravity (g/cm^3)	Water Absorption (%)
Artificial Aggregate	4-11	2.5	1.5	27,5

The natural sand used in the experimental study was supplied from Gaziantep-Center and the maximum grain size is 4 mm. The saturated dry surface specific gravity of the supplied sand was determined in accordance with TS EN 1097-6 and is given in Table 3.

Table 3. Properties of natural sand

Types of Aggregates	Sieve Size (mm)	SSD Bulk Density (g/cm^3)	Specific Gravity (g/cm^3)	Absorption Capacity (%)
Sand	0-41	0.72	2.6	1.7

The natural bentonite clay mineral used in the experimental studies was provided by from Malatya region and supplied has a beige-green color and fine in structure.

For the concrete samples produced in the experimental studies, CEM II 42.5 R Portland cement in accordance with TS EN 197-1 [10] was used. Some physical, chemical and mechanical properties of the cement used are given in Table 4.

Table 4. Portland cement properties

Chemical Composition		**Physical and Mechanical Properties**	
Components (%)		Specific Gravity (g/cm^3)	2,98
SiO_2	23,36	Specific Surface (cm^2/g)	3610
Al_2O_3	7,98	Residue on 0,032 mm	14,0
Fe_2O_3	3,5	Residue on 0,090 mm	0,6
CaO	54,03	Initial Setting Time (min)	190
MgO	1,81	Final Setting Time (min)	320
K_2O	0,92	Soundness	1
Na_2O	1,23	Normal Consistency	30,3
SO_3	3,40	**Mechanical Properties**	
Cl^-	0,073	Compressive Strength N/mm^2	
Free CaO	2,32	2 Days	30,5
Loss on Ignition	2,85	28 Days	58,7

Tap water supplied from Gaziantep city network was used as mixing water in the preparation of concrete mixtures. During the production of concrete samples, Master Glenium ACE 30, a superplasticizing concrete additive was used to reduce the current water requirement and increase workability.

2.2. Method

During the planned experimental processes, 5 series of concrete samples were produced, one of which was produced as a control and samples have been prepared in accordance with TS EN 206-1 [11] in the Construction Laboratory of Gaziantep University. Samples mixtures were produced by replacing 0%, 5%, 15% and 30% by volume of the cement used as a binder with bentonite clay. Thus, the effects of bentonite clay mineral on mortar properties and hardened concrete were observed.

The bentonite clay used in the experimental studies was dried in an ALFA brand drying oven at 60˚C for 24 hours and after drying, it was ground using a disc grinding mill to pass through a 0.125 mm sieve. The material which was ground in a disc mill for 15 minutes and passed through a 0.125 mm sieve, was used as a cement replacement material. In the coding of the samples N for the control samples and B code were used for the doped (bentonite used) samples. Code B0 was used for samples without bentonite substitute, code B5 for samples with 5% bentonite content, code B15 for samples with 15% bentonite content, and code B30 for samples with 30% bentonite content. Prepared of concrete mixtures particular composition and labelling are presented in following Table 5.

Table 5. Composition of concrete mixtures (kg / m³)

COMPONENT	N	BO	B5	B15	B30
Cement (kg)	10.8	10.8	10.26	9.18	7.56
Water (lt)	4.73	4.77	5.0	5.2	7.1
Chemical Additives (g)	133.3	133.3	144	156	216
Natural Aggregates (kg)	20.2	17.68	17.68	17.68	17.68
Artificial Aggregate (kg)	_	2.21	2.21	2.21	2.21
Natural Sand (kg)	22	22	22	22	22
Bentonite Clay (kg)	_	_	0.54	1.62	3.24
Water / Cement	0.44	0.44	0.49	0.57	0.94
Water / Binder	0.035	0.036	0.035	0.033	0.033
Slump / Flow (cm)	1	75 (Flowed)	70 (Flowed)	3	5

3. EXPERIMENTS AND RESULTS

3.1. The tests performed

In this experiments performed on fresh concrete, slump frustum of cone with a lower diameter of 200 mm, an upper diameter of 100 mm and a height of 300 mm according to TS EN 12350-2 [12] standard was used. The slump test performed is shown in Figure 1. The prepared mixtures were subjected to the flow-table test, which is another consistency test. In accordance with TS EN 12350-5 [13], both the width and length of the concrete were determined in the flow- table and recorded by taking the average. Slump test and flow-table test results are shown in Table 6.

According to the results obtained in the slump test performed to measure the workability-consistency degree of the test samples, the lowest slump amount was obtained in the control group (N) and the highest slump value was obtained in the B30 group. S1 consistency degree for control sample N and B15 sample; for the B30 sample consistency degree is S2. With the TS EN 206-12 draft, the fluiding class of 2 series (B0 and B5 series) of self-compacting concrete has been determined as SF2.

Table 6. Slump / Flow-table test results

Concrete Mix	Slump / Flow (cm)
N	1 cm
B0	Flowed / 75 cm
B5	Flowed / 70 cm
B15	3 cm
B30	5 cm

3.2. Compressive Strength Tests

The samples soaked in water with a temperature of 21±2 ^{0}C were removed from the curing pool one day before the 7th and 28th days. After waiting for their surfaces to dry, cube samples of 100x100x100 mm were then subjected to compressive strength tests on the 7th and 28th days. ELE brand AUTOTEST 3000 type press with a capacity of 300 tons was used to determine the compressive strength of the samples and the head surfaces of the press machine were cleaned during loading. Care was taken to ensure that there was no protrusion or roughness on the surfaces of the samples that would touch the caps. All of the samples were broken under the same compressive machine, the 7 and 28-day sample series was broken with a constant loading speed within itself. After the breaking loads were found in Newtons (N), they were divided by cross-sectional areas and calculated in the unit of compressive strengths (N/mm^2).

For each mixture, compression tests were carried out on 3 different samples produced. The compressive strength was calculated using the equation given below.

$$f_c = \frac{F}{A_c}$$

where f_c is the compression strength, MPa or N/mm^2 and A_c is the cross-sectional area, mm^2

Figure 1. Compression test device

3.2.1. Compression Test Results of 7-days

In this section, the test results were examined for each series produced and the 7-day cubic compressive strengths of the produced concrete are calculated.

It is seen that, the highest compression strength value is in BO and B5 samples, the lowest compression strength value is in the B30 sample in the 7-day strength results. If the control (N) samples are taken as a reference in the 7-day strength results B0 and B5 series have 146% higher strength. In the prepared B30 mixture it is seen that there was a decrease of 19.5% strength compared to the control sample.
It is seen that, the bentonite unsubstituted series prepared by using artificial aggregate and the series with 5% bentonite substituted ratio have almost the same strength value and have a 146% higher strength value than the control sample. If the bentonite substitute ratio is 15% the compressive strength was not affected more positively or negatively than the control sample. It is seen that the compression strength of the samples containing 30% bentonite is lower than the strength of the control mixture of the same age and it can be seen that the compressive strengths of the B30 series develop more slowly in the first days.

3.2.2. Compression Test Results of 28-days

The cube compressive strengths of the concrete samples for 28-days are given in Figure 2.

The International Journal of Energy & Engineering Sciences, 2023, 8 (1) 1-8
ISSN: 2602-294X - Gaziantep University

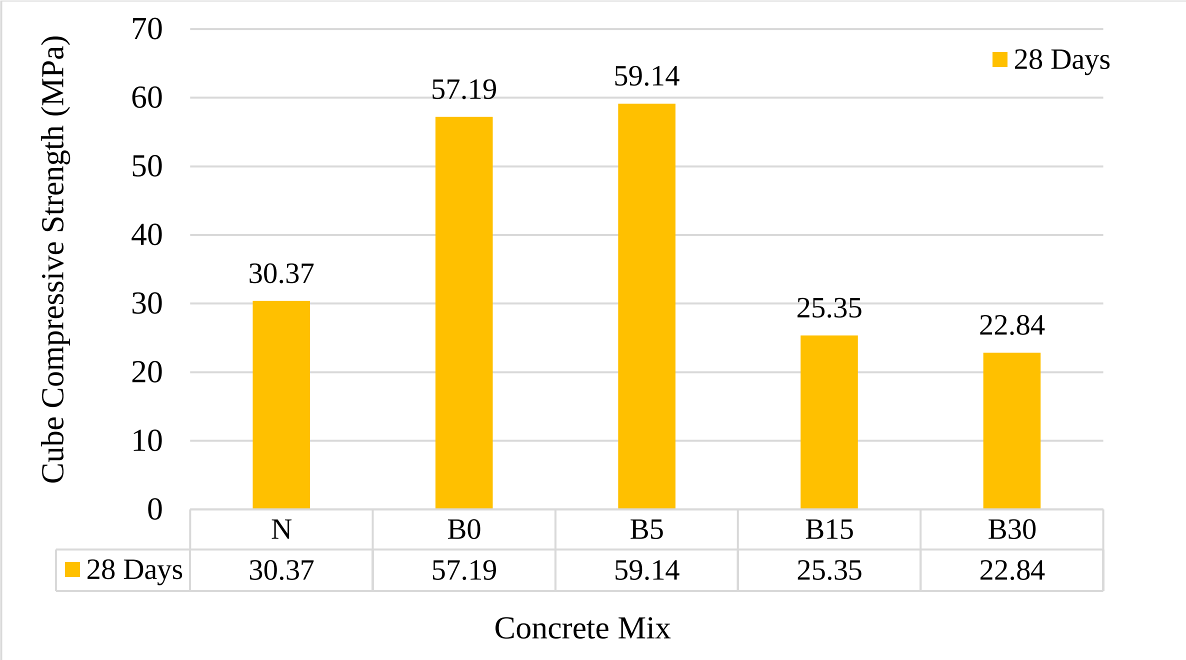

Figure 2. Compression test results of 28 days

It is seen that, the highest strength value in the results of 28-day cube compression test is in the B5 series and the lowest strength value is in the B30 series. If the control (N) series are taken as a reference in the 28-day strength results, the B5 series have 94.7% higher strength values and BO series have 88.3% higher strength. It is seen that the B15 series had 16.5% lower strength and the B30 series had 24.8% lower strength.

3.2.3. Comparison of 7 and 28-day Compression Test Results

The average cube compressive strength values of the samples for 7 and 28 days shown in Figure 3.

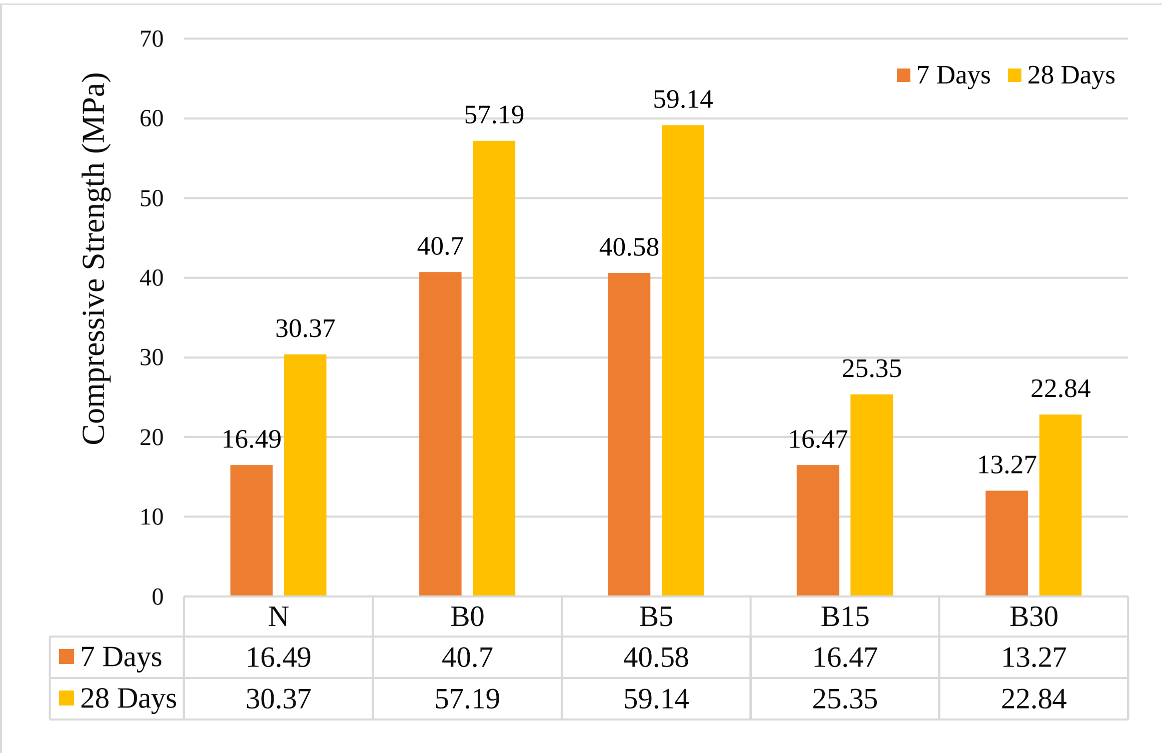

Figure 3. Comparison of 7 and 28-days compression test results.

According to the test results given in Table 8, it is seen that the highest 7/28 ratio is 0.71 in the bentonite unsubstituted B0 series and the lowest 7/28 ratio is 0.54 in the control sample. The 7-day strength of the B15 series is close to the reference sample strength. However, it was observed that there were decreases in 28-day strength compared to the reference sample. It was observed that the 7 and 28-day compressive strength values of the 30% bentonite added mortars did not meet the strength of the reference sample.

4. CONCLUSIONS

This article is focused on the designing of a new kind of concrete with high strength for future application. For that purpose, new concrete mixtures were prepared by bentonite with which were added as a partial cement replacement application of bentonite was mainly as an admixture in several replacement levels. The main emphasis was given to mechanical properties of prepared concretes and the contribution of replacing Portland cement by volume with bentonite clay to the concrete samples in terms of compressive strength was investigated. The following conclusions and recommendations could be drawn from the experimental results:

- The slump test performed to measured the workability-consistency degree of the test samples, the lowest slump amount was obtained in the control group (N) and the highest slump value was obtained in the B30 group. S1 consistency degree for control sample N and B15 sample; for the B30 sample consistency degree is S2. Based on the values found, it was observed that the amount of slump changes depending on the amount of use of bentonite clay mineral instead of cement, and the amount of slump increased as the amount of bentonite clay increased. In this respect, the greater the amount of slump, the higher the degree of workability of the fresh concrete and it is proportional to the concretes ability to move under its own weight.
- The flowing class of 2 series (B0 and B5) of self-compacting concrete has been determined as SF2.
- At the ages of 7 and 28 days, it was observed that the B5 samples of the produced bentonite mortars reached the best compressive strength values. The application of bentonite in general caused fall of compressive strength but content of 5% bentonite caused rise of compressive strength. 5% bentonite based concrete showed appropriate properties, the rise of compressive strength was sufficiently and reached sufficient values.
- The 28-days compressive strength results of the series were found to be better in groups B0 and B5 and lower in groups B15 and B30 compared to the control sample. The best strength value was determined in the B5 series and it was observed that 5% bentonite substitute has a good effect on compressive strength. It is thought that bentonite shows pozzolanic properties due to the effect of SiO_2 contained in it and has a filling effect in the cavities of the concrete sample.

REFERENCES

[1] Grım, R. (1968). *Clay Mineralogy*. 2nd edition. New York: McGraw-Hill.

[2] İşçi, S. (2002). *Bentonit Dispersiyonlarına Organik ve İnorganik Katkıların Absorbsiyonun Reolojik Özellikleri Üzerine Etkisi.* Yüksek Lisans Tezi, İstanbul Teknik Üniversitesi Fen Bilimleri Enstitüsü, İstanbul.

[3] Chimeddorj, M. (2007). *Farklı Bentonitlerin Nem Alıcı (Desikant) Özelliklerinin Belirlenmesi.* Yüsek Lisans Tezi, İstanbul Teknik Üniversitesi Fen Bilimleri Enstütüsü, İstanbul.

[4] Dağ, S. E. (2018). *Polimer/Montmorillonit Kompozitlerin Kimyasal Yöntemle Hazırlanması ve Özelliklerinin Belirlenmesi.* Doktora Tezi, Ankara Üniversitesi Fen Bilimleri Enstitüsü, Ankara.

[5] Eruslu, N. (1993). *Türkiye bentonitleri ve döküm kumları araştırma projesi.* DPT Teknolojik Araştırma Projesi.

[6] Akbulut, A. (1996). Bentonit. *Maden Tetkik ve Arama Genel Müdürlüğü Eğitim Serisi No:32*, (s. 1-86). Ankara.

[7] Çinku, K. (2008). *Aktivasyon Yöntemleri İle Bentonitten Su Bazlı Kıvamlaştırıcı Üretiminin Araştırılması.* Doktora Tezi, İstanbul Üniversitesi Fen Bilimleri Enstitüsü, İstanbul.

[8] Kaya, T., & Yazıcıoğlu, S. (2015). Kalsine bentonit katkılı harçların fiziksel ve mekanik özelliklerine yüksek sıcaklık etkisi. *BEU Journal of Science*, **4(2)**, 150-160.

[9] Turkish Standard TS EN 1097-6. (2002). *Determination of particle density and water absorption*.

[10] Turkish Standard TS EN 197-1. (2002). *Compositions and Conformity Criteria for Common Cements*.

[11] Turkish Standard TS EN 206-1. (2002). *Specification, performance, production and conformity*.

[12] Turkish Standard TS EN 12350-2. (2002). *Testing fresh concrete - Part 2: Slump Test*.

[13] Turkish Standard TS EN 12350-5. (2010). *Testing Fresh Concrete - Part 5: Flow table test*.

[14] Atmaca, N., Atmaca, A., Özçetin, A. İ. (2021). The impacts of restoration and reconstruction of a heritage building on life cycle energy consumption and related carbon dioxide emissions. Energy and Buildings 253, 111507. https://doi.org/10.1016/j.enbuild.2021.111507

[15] Atmaca, A. (2017). Sustainable life span prediction of shelters constructed in refugee camps in Turkey. Energy, Ecology and Environment 3 (1) 5–12. Springer Science and Business Media LLC. https://doi.org/10.1007/s40974-017-0053-z

[16] Atmaca, A., Kanoglu, M., Gadalla, M. (2012). Thermodynamic analysis of a pyroprocessing unit of a cement plant: a case study. International Journal of Exergy 11, 2, 152. https://doi.org/10.1504/ijex.2012.049740

[17] Atmaca, A., Yumrutaş, R. (2015). The effects of grate clinker cooler on specific energy consumption and emissions of a rotary kiln in cement industry. In International Journal of Exergy 18,3,367. https://doi.org/10.1504/ijex.2015.072897

[18] Atmaca, A., Atmaca, N. (2022). Carbon footprint assessment of residential buildings, a review and a case study in Turkey. Journal of Cleaner Production 340, 130691. Elsevier BV. https://doi.org/10.1016/j.jclepro.2022.130691

[19] Atmaca, A. (2023). Detailed assessment of specific exergetic costing, energy consumption, and environmental impacts of a rotary kiln in cement industry. Environmental Science and Pollution Research 30, 14, 40260–40282. Springer Science and Business Media LLC. https://doi.org/10.1007/s11356-022-24882-w