Research Article

Physicochemical Properties of Handere Clays and Their Use as a Building Material

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Handere clay deposits were discovered at Adana in Turkey. These clay units primarily consist of uncoloured claystone, pebbly sandstone, sandstone, siltstone, and mudstone marl and include gypsum lenses and clay levels of various thicknesses in places. The physicochemical properties of these clays have been investigated by different techniques including Scanning Electron and Elemental Analysis (SEM and EDS), mineralogical analyses, chemical and physical analyses, X-ray diffraction (XRD), thermogravimetric differential thermal analysis (TG-DTA), and Atterberg (Consistency) Limits Test. The mineralogical composition deduced from XRD is wide (smectite + palygorskite + illite ± feldspar ± chlorite ± quartz ± calcite ± serpentine) due to the high smectite contents (≈85%). SEM studies reveal that smectite minerals are composed of irregular platy leaves and show honeycomb pattern in the form of wavy leaves in places. The leaves presenting an array with surface edge contact are usually concentrated in the dissolution voids and fractures of volcanic glass. Organic matter content and loss on ignition analysis of raw materials are good for all the studied samples. In summary, Handere clays can be used as building materials in bricks, roof tiles, and cement and as a binder.

1. Introduction

Human beings found various applications of layered clay minerals since prehistoric civilization due to their widespread distribution and a great diversity of reactions in nature. Depending on the layer structure and specific properties, such as high specific surface area, ion exchange capacity, or hydration property, clay minerals were widely used in ceramics and building materials, paper industries, oil drilling, foundry moulds, and pharmaceuticals and were also used as adsorbents, catalysts or catalyst supports, ion exchangers, and decolourizing agents [1–5].

Clay minerals are a class of phyllosilicates which usually form as a result of chemical weathering of other silicate minerals at the surface of the earth. This mineral mostly contains limestone, silica, mica, and iron oxide and has a yellowish, reddish, or brown colour. Clay is a valid concept for decomposition products generated by hydrothermal activity and for particles deposited by sedimentation, and chemical classifications were made according to the minerals comprising such small particles [6–10].

Clay minerals are included in kaolinite, halloysite, illite, chlorite, smectite, and attapulgite groups according to their chemical composition and formation. Clay minerals which used to be called montmorillonite group are referred to as smectite. Smectite minerals are composed of two silica tetrahedral layers and a single Al octahedral layer. Important smectite group minerals include montmorillonite, beidellite, nontronite, hectorite, saponite, and sauconite. The minerals in this group have a density of 2–3 gr/cm³ and hardness between 1 and 2 [11–13].

Depending on the amount of water mixed into them, clays exhibit a variety of properties, including plasticity, fluidity, and colloidal and thixotropic properties. These various properties affect industrial and engineering use of clay minerals [14–18]. Chemical composition of various clay minerals was presented in Table 1.

In this study, Handere clays were investigated in order to characterise the raw material available at Adana in Turkey. The study covered over approximately 20 km including Handere formation (Figure 1).

TABLE 1: Chemical composition of various clay minerals [17].

Clay	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MgO	CaO	K ₂ O	Na ₂ O	TiO ₂	H ₂ O	Total
Kaolinite	46.90	37.40	0.66	0.27	0.29	0.84	0.44	0.18	12.95	99.92
Nacrite	44.75	39.48	0.53	0.19	0.13	0.34	0.22	—	14.40	100
Stalagmites	46.86	37.12	1.43	0.09	0.22	0.60	0.07	0.51	12.99	99.89
Halloysite	44.75	36.94	0.31	—	0.11	0.60	—	—	17.42	100.01
Anauxite	54.32	29.96	2.00	0.14	0.32	—	0.37	—	12.64	99.75
Nontronite	40.54	5.19	31.63	0.06	1.92	0.24	0.14	—	20.75	100.47
Chlorite	31.44	17.62	—	37.64	—	—	—	—	13.19	99.89
Prochlorite	23.69	21.26	26.52	17.60	3.22	—	—	—	7.63	99.92
Sepiolite	52.50	0.60	2.99	21.31	0.47	—	—	—	21.27	99.14
Attapulgit	57.85	7.89	2.82	13.44	0.30	0.08	0.53	—	16.95	99.86

FIGURE 1: Location of studied area at Handere in Turkey.

Their best uses require an exact knowledge of their physicochemical properties. This paper describes studies of crude clay samples with a set of techniques comprising mineralogical analyses, Scanning Electron Microscope (SEM), Elemental Analysis (EDS), chemical and physical analyses, X-ray diffraction (XRD), thermogravimetric-differential thermal analysis (TG-DTA), and Atterberg (Consistency) Limits Test. In addition, organic matter content and loss on ignition analysis of raw materials test were performed for determination of applicability of the material as a building material. The work had three distinct aims:

- (1) To identify Handere clay present in different samples and its purity and associated minerals.
- (2) To characterise the physicochemical properties of the clay to enable assessment of its suitability for different uses.
- (3) To determine applicability of the material as a building material.

2. Geological Description of Handere Clays

Clay deposits investigated in the present study are from a cluster at Adana in Turkey. Handere geological formation was named by Schmidt in 1961 [19]. The unit primarily consists of uncoloured claystone, pebbly sandstone, sandstone, siltstone, and mudstone marl and includes gypsum lenses and clay levels of various thicknesses in places. Trough cross-stratification in pebbles and parallel lamination in those with tiny particles are observed. The thickness of the formation is in the range of 120 to 700 m [20]. The bottom unit has a transitional contact on Kuzgun formation, and the top unit covered by young alluvial deposits in places has a widespread terrace set formation of Adana basin. According to the fossil groups discovered in the formation, the formation is assigned a Messinian-Pliocene age. The study samples representative of the area were collected, classified by sieving them (0.2 to 2 mm) at the laboratory, and made ready for tests [21–24].

3. Chemical Composition

Samples representative of the area were collected from Handere formation and chemical analyses were performed in order to determine their chemical composition. Chemical analysis of the samples was performed using XRF device (Siemens SRS 300 X-Ray Fluorescence Spectrometer) after they were dried at 105°C. The results obtained from the analyses are given in Table 2. When the results were interpreted, it was identified that the clay content (%) is largely composed of SiO₂ (mean: 61.71 ± 0.21) and Al₂O₃ (mean: 16.42% ± 0.58) and the clay group contains smectite mineral, and these results were consistent with previous studies in the literature.

4. Petrographic Studies

Thin sections with a thickness of 0.02 mm were prepared from clays. These sections were examined by polarizing microscope. As a result of their microscopic examinations, it was determined that the clay is smectite, a type of clay mineral rich in silica (Si) and aluminum (Al). The smectite mineral was found to contain amorphous silica, calcite, chlorite, quartz, and illite minerals.

TABLE 2: The results of chemical analysis of Handere clay (%).

Chemical composition	Mean	Standard deviation
SiO ₂	61.71	0.21
Al ₂ O ₃	16.42	0.58
Na ₂ O	2.26	0.19
K ₂ O	4.58	0.24
Fe ₂ O ₃	7	1.76
CaO + MgO	3.92	0.33
Others	4.12	1.83

FIGURE 2: X-ray diffraction patterns for a Handere clay sample (glycol solvated).

5. Mineralogical Composition (XRD)

Mineralogical analysis was conducted on the samples in powder form by Cu X-ray tube Rigaku Geigerflex XRD apparatus. As a result of phase (mineralogical) analysis, it was revealed that the clay samples are largely comprised of smectite 14 (85%), followed by palygorskite, illite, feldspar, chlorite, quartz, calcite, and trace amounts of serpentine in decreasing order of abundance (Figure 2).

6. Scanning Electron Microscope (SEM)

Clay samples were enlarged in the range of 105–170 μm and were examined by image analysis system and their photographs were taken (Figure 3). It is clear that clay samples are smectite clay minerals. Smectite minerals are composed of irregular platy flakes and show honeycomb pattern in the form of wavy leaves in places. The flakes presenting an array with surface edge contact are usually concentrated in the dissolution voids and fractures of volcanic glass. In addition, smectite flakes show growth towards the pores.

FIGURE 3: SEM image of Handere clay (smectite).

7. Elemental Analysis (EDS)

SEM analysis and EDS (energy dispersive spectrometer) and point (elemental) analyses of the samples were performed and distribution percentages of the elements were determined. EDS point analysis was conducted using EDAX Genesis XM 4i model detector. The clay samples were identified to have oxygen (46.95%), silica (27.3%), aluminum (7.11%), and iron (2.53%) (Figure 4).

8. TG-DTA Analysis

According to TG curve of the clay (smectite) sample, the sample lost its moisture at about 50–100°C. In DTA analysis, the mass loss was not significant until 480°C, and the endothermic peak at 713.4°C supported that thermal degradation took place between 480 and 800°C. In TG curve, it was determined that there was no mass loss after 790°C and the total mass loss was about 5.5%. Sintering started at around 440°C and was complete at 700°C. The reaction decomposition started at 810°C, made an endothermic peak at about 834.6°C, and was complete at 855°C (Figure 5). In a literature review, it has been found to show similar characteristic of clay in the Mediterranean zone [12, 21, 25–27].

9. Physical Properties

In order to determine the physical properties (loose unit weight, specific gravity, porosity, water absorption, and compactness ratio) of Handere clays, the samples were ground and sieved through sieves with 1 mm of sieve opening and their impurities were removed. Their loose unit weight analyses were conducted in accordance with TS 3529 and TS 1114 standards [28, 29]. The results obtained from the analyses are given in Table 3.

10. Atterberg (Consistency) Limits Test of Handere Clays

Water content values defined by Atterberg, a Swedish chemist, are used to determine consistency limits of soils

FIGURE 4: EDS analysis of Handere clay.

FIGURE 5: Clay example 20°C/min. heating rate conversion TG-DTA curves.

TABLE 3: The results of the physical analysis of Handere clay.

Tests	Mean	Standard deviation
Unit weight (gr/cm ³)	1.32	0.06
Specific gravity (gr/cm ³)	2.73	0.02
Porosity (%)	12.80	1.60
Water absorption (%)	52.64	2.65
Compactness ratio (%)	0.46	0.03

[30]. In the present study, Casagrande method was used to determine the consistency limits of Handere clays [31].

As a result of the test, liquid limit and plastic limit were 52% and 23%, respectively. According to these results, calculated plasticity index, PI, was 29%, and the soil class was identified as highly plastic clay.

11. Tests for Determination of Applicability of the Material as a Building Material

Limit values of a material to be used in the building and construction sector should be determined by examining the general structural characteristics of that material. For this purpose, whether the clay mineral is suitable to be used as a building material was investigated by organic matter content and loss on ignition analyses.

12. Organic Matter Content

Presence of organic matters in a raw material is inconvenient and undesirable. Organic compounds particularly reduce the strength of a building material, cause corrosion and softening in the material over time, and, most importantly, make natural and chemical materials, which are used as binders, lose their binding properties. As a result of the test conducted according to the test criteria indicated in TS EN 1744-1 and TS 4790 [32–34], Handere clays were found to contain no organic matter. The results of chemical analysis conducted on the clay are consistent with the results obtained from this test.

13. Loss on Ignition Analysis of Raw Materials

At high temperatures, as in the case of a fire, the composition of aggregate and natural binder materials, used in the manufacture of building materials in the construction industry, deteriorates, and such materials undergo mass loss. Therefore, whether a raw material intended for use in the construction industry undergoes any mass loss as a result of the effect of temperature should be determined.

According to the results obtained from loss on ignition analyses, loss on ignition of Handere clays was determined as 4.85%. As stipulated in the standard, TS 1114, the maximum loss on ignition of a raw material can be 5% by weight. TS 1114 stipulates that if the loss by weight of a raw material at maximum temperature is $\leq 5\%$, it can be used as a raw material in bricks, cement, and roof tiles.

According to the analysis results, it was determined that the clays of the region can be used as building materials in bricks, roof tiles, and cement and as a binder; however, they cannot be used in the production of ceramics, porcelain, glass, and tiles.

14. Conclusion

In this study, material properties of the clays from Handere formation were investigated in order to determine their applicability as a building material. As a result of petrographic and chemical analyses, it was determined that the clays were smectite, a clay mineral rich in Si and Al. The smectite mineral was found to contain amorphous silica, calcite, chlorite, quartz, and illite. According to the results of qualitative mineralogical (XRD) analyses, the samples were found to be largely comprised of smectite 14 (85%), followed by palygorskite, illite, feldspar, chlorite, quartz, calcite, and trace amounts of serpentine in decreasing order of abundance.

In SEM examinations, it was seen that the clay samples are smectite clay minerals. Smectite minerals are composed of irregular platy leaves and show honeycomb pattern in the form of wavy leaves in places. In elemental (EDS) analyses, the clay samples were identified to have oxygen (46.95%), silica (27.3%), aluminum (7.11%), and iron (2.53%).

In TG-DTA analysis, the mass loss was not significant until 480°C, and the endothermic peak at 713.4°C supported the fact that thermal degradation took place between 480 and 800°C. In TG curve, it was determined that there was no mass loss after 790°C and the total mass loss was about 5.5%.

Consistency limits of Handere clays were established, and, at the end of the test, a liquid limit of 52% and a plastic limit of 23% were found. According to these results, calculated plasticity index was 29% and the soil class was identified as highly plastic clay.

As a result of the studies performed according to test criteria specified in EN 1744-1, no organic matter was found in Handere clays. According to the results of loss on ignition analyses conducted according to TS 1114 standard, loss on ignition of Handere clays was 4.85%. When the results were examined, loss on ignition of the clays was less than 5%, so it was determined that the clays can be used as aggregate raw materials in the production of bricks and lightweight building materials.

In conclusion, when the studies and the analysis results were evaluated together, it was established that the clays from the region can be used as building materials, including bricks, roof tiles, and fillers; however, they cannot be used in the production of ceramics, porcelain, glass, and tiles.

Conflict of Interests

The author declares that there is no conflict of interests regarding the publication of this paper.

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