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Characteristics and Ceramic Properties of Turgutlu Clay

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The aim of this study is to characterize and determine the ceramic properties of the Turgutlu clay fired at various temperatures. For this purpose, the clay sample was first characterized by chemical analysis, X-ray diffraction, and plasticity measurements. The mineralogical composition of the Turgutlu clay was dominated by quartz, illite, mica, hematite, calcite, kaolinite, microcline, and smectite. The data obtained from plasticity tests indicated that the Turgutlu clay was very high plastic clay. To evaluate firing behaviors, pressed clay samples were fired separately at temperatures between 850 and 1100 °C. Fired specimens were evaluated by water absorption, linear shrinkage, bulk density, flexural strength, X-ray diffraction, and scanning electron microscopy. Significant changes were observed such as an increase in the linear shrinkage and flexural strength together with a decrease in the water absorption above 1050 °C. Based on the technological characteristics, the Turgutlu clay could be used in the manufacture of structural ceramics.

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1. Introduction

Clay minerals have been used as raw materials in many industrial fields for ages due to their physicochemical properties and their abundance associated with their relatively low cost. Worldwide, clayey materials are the main raw materials in production of traditional ceramics. Applications of the clay minerals depend on their compositions, structures and physical properties. Clays undergo a lot of physical and chemical changes which determine predominantly their ceramic properties during firing. The changed physical and chemical properties of the clay minerals with firing temperature determine their uses as an industrial ceramic raw material. For economic reasons, ceramic industry prefers to use clayey materials from nearby deposits. As a consequence, the characterization and ceramic properties of the clay minerals are important for their performance [1–8].

In the Aegean region of Turkey there are extensive red firing clay deposits. These clays are currently being used for traditional pottery and brick production. In the region of Turgutlu, red firing plastic clays are used for the production of brick-tile. There are nearly 70 factories and 1,117,000,000 pieces of brick and tile are produced per year [9, 10]. The Turgutlu clay (TC) is a primary material for the local factories.

Although very limited studies on the characterization of TC have been reported in the literature [10], ceramic properties of TC have not been studied. To be able to fill this gap in the literature, the present study was carried out to: (a) determine the characteristics of the clay and (b) examine the ceramic properties. These data are very crucial for evaluating their potential suitability as raw materials in various ceramic applications.

2. Material and equipment

The clay investigated in this work was obtained from Turgutlu that is a district of Manisa, Turkey. In this research, the clay sample was obtained from a deposit located in Turgutlu (Manisa). This deposit is representative and currently used for ceramic production. The clay was characterized by chemical and X-ray diffraction (XRD) analyses. The chemical composition of clay samples was analyzed by atomic absorbtion spectroscopy (GBC). The phases present in the samples were identified by X-ray diffraction (XRD) using a Rigaku Model diffractometer with monochromotic Cu K_α radiation. The plasticity was measured by the Atterberg limits: plastic limit, liquid limit, and plastic index, according to the ASTM, D 4318-10 norms [15].

Preparation and testing of the samples were done on a laboratory scale. In order to enlighten the ceramic properties pellet clay samples were used. To produce pellet samples, clay sample was dried and ground. The ground agglomerates were then humidified up to 6 wt% water. The humid powders were pressed under 150 kg/cm^2 pressure to obtain $100 \times 50 \times 6$ mm^3 prismatic samples. The shaped samples were dried at 120 °C for 24 h and fired at 850, 900, 950, 1000, 1050, and 1100 °C using a laboratory kiln (Nabertherm LH 15/14). Fired samples were used to characterize the physical properties of the materials according to TS EN ISO 10545-3 and TS EN ISO 10545-4 norms [16, 17]. Phase changes with increase of temperature were investigated by X-ray diffraction. The microstructures of the fired samples were analyzed by a scanning electron microscope, SEM (JEOL-JSM 6060).

3. Results and discussion

The chemical composition in terms of oxide contents, as well as loss of ignition for TC is listed in Table I. This clay shows expected typical composition that consists of mainly SiO$_2$ and Al$_2$O$_3$ which corresponds to about 71%

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because of the presence of clay minerals and quartz. Also, as typical Aegean region clay [11], these oxides are accompanied by a significant amount of iron oxide which is responsible for the reddish color after firing [12]. The high ignition loss (LOI) is due to the presence of volatiles, comprising in clay minerals and calcite. Figure 1 shows the result of XRD analysis of whole rock TC sample. The mineral assemblage of the TC sample is dominated by quartz, mica, plagioclase, smectite, chlorite, kaolinite, and calcite.

TABLE I

Chemical analysis results of TC.

Oxides [wt%]	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	LOI
TC	58.50	17.17	6.55	1.69	2.38	0.99	2.96	0.85	8.50

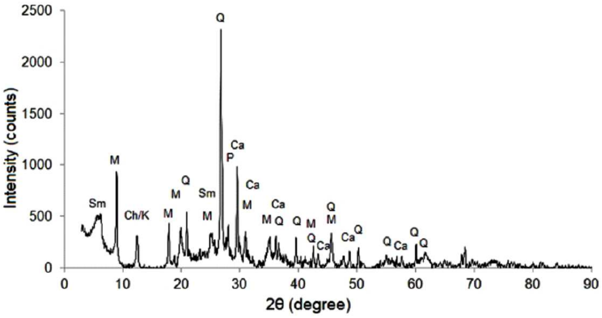

Fig. 1. XRD pattern of the whole rock from TC.

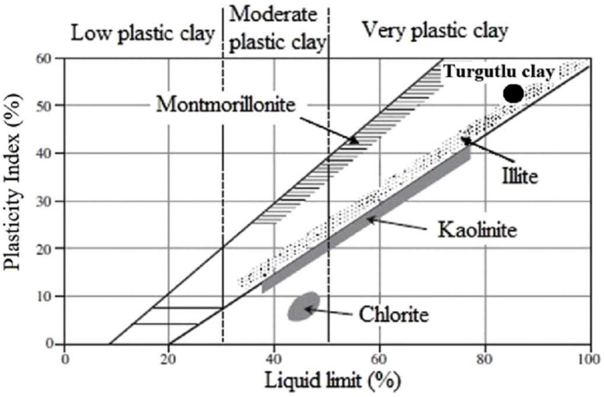

Fig. 2. Position of clay sample on the Holtz and Kovacs diagram.

Plasticity is one of the most important parameters for manufacturing clayey products. The plastic limit, liquid limit and plasticity index values of TC were found to be 35, 86, and 51%, respectively. The plasticity index and liquid limit of the clay sample indicate that it belongs to the very plastic clay region on the Holtz and Kovacs diagram (Fig. 2).

For practical purposes, the plasticity index values lower than 10% are not suitable for ceramic production, due to the risk of cracking during the extrusion process. The plasticity index should be above 10% and TC meets this suitable value [13].

Figure 3 shows the diffraction patterns of the clay samples after firing for 30 min between 850 °C and 1100 °C. During heating decomposition and phase transformation processes take place [4, 14]. At 850 °C, the peak of kaolinite is not seen due to the transformation of kaolinite into metakaolinite. Quartz, hematite and illite peaks are still seen. At 1000 °C it can be seen that the peaks of illite have disappeared and at 1050 °C, cristobalite and mullite phases begin to develop.

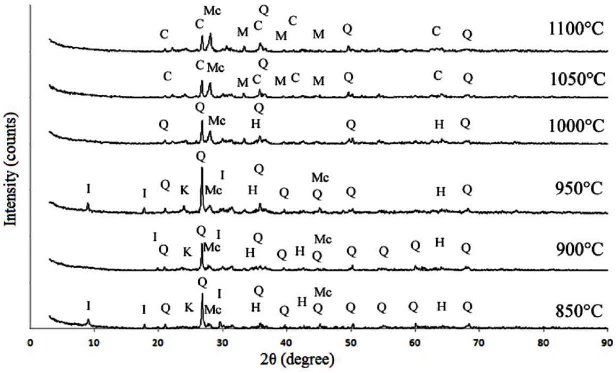

Fig. 3. XRD patterns for TC samples fired at different temperatures (abbreviations: Q — quartz, I — illite, H — hematite, Mc — microcline, M — mullite, C — cristobalite).

TABLE II

Physical properties of the clay fired at different temperatures.

Temperature [°C]	Water absorption [%]	Linear shrinkage [%]	Flexural strength [MPa]	Bulk density [g/cm^3]
850	17.08	2.30	3.41	1.80
900	16.47	2.73	4.87	1.81
950	15.13	3.19	6.49	1.84
1000	14.15	3.42	9.21	1.86
1050	12.00	3.94	12.56	1.90
1100	8.96	5.36	16.76	1.99

In Table II, water absorption, linear shrinkage, flexural strength and bulk density values of the clay samples fired at different temperatures are shown. The results indicate that there is a moderate change from 850 to 1050 °C. As temperatures increases, there becomes a liquid phase formation that reduces the volume of the open pores by penetrating them. The volume of the open pores affects the water absorption values. The water absorption is closely related to densification [4]. The densification behavior of the clay samples is influenced by the flux content (K_2O, Na_2O and Fe_2O_3). Although TC has low amount alkaline fluxes (Table I), it is reasonable to think that the high amount of iron oxide plays a key role on densification. This promotes the formation of glassy phase [12]. As a result, the water absorption values tended to decrease and linear shrinkage values tended to increase with increase of temperature and the greatest tendency was found at and above 1050 °C.

The results of flexural strength tests are quite correlated to all the other studied parameters. It is known that porosity has negative influence on the flexural strength. It was observed that flexural strength values increase with temperature due to the sintering. The flexural strength increases from 3.41 MPa to 16.76 MPa as a result of decreasing porosity and significant development of the liquid phase. Therefore, the pore closure must cause an increase of the flexural strength. The bulk density values behave differently below and above 1050 °C. This behavior is firmly correlated with the densification behavior discussed above. The bulk density values vary between 1.80% and 1.99%.

Figure 4a–d shows the microstructure of the clay samples fired at various temperatures. SEM micrographs, taken at increasing firing temperatures, show the typical sequence of enhanced densification with increase of temperature. Between 850 and 1000 °C, sample surfaces have microscopic pores and voids. It is reasonable to think that microstructural features remain unchanged up to 1000 °C. Above 1000 °C the grains of the clay minerals coalesce and porosity starts to reduce. It can be thought that a liquid phase starts to emerge at 1050 °C and the porosity on the sample surface becomes lesser due to the liquid phase. At 1100 °C, due to the liquid phase formations, the structure is very dense. Additionally, some pores still can be seen.

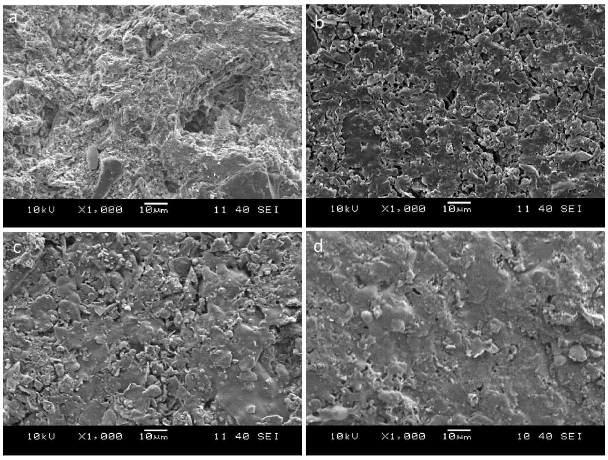

Fig. 4. SEM micrographs of the clay samples fired at: (a) 850 °C, (b) 950 °C, (c) 1000 °C, and (d) 1100 °C.

4. Conclusion

In this study, the characteristics and ceramic properties of the Turgutlu (Manisa) clay were investigated. From the results obtained, the following conclusions can be drawn.

The predominant oxides in TC are SiO_2, Al_2O_3 and Fe_2O_3. Quartz, mica, plagioclase, smectite, chlorite, kaolinite, and calcite are found as the main phases. The plasticity index indicated that TC is very high plastic clay that is suitable to form a plastic body.

The ceramic properties of TC were evaluated by water absorption, linear shrinkage, bulk density, flexural strength, X-ray diffraction, and scanning electron microscopy. The changes in the physical properties were moderate up to 1050 °C. Especially at 1050 °C, significant increase in the bulk density and linear shrinkage was observed whereas water absorption values decreased. During firing phase transformation occurred and ultimate phases obtained were cristobalite, mullite, quartz and microcline. SEM micrographs, taken at increasing firing temperatures, show the reduction of porosity and the progression of enhanced densification with increase of temperature. In view of these evaluations, this raw material is suitable for porous structural ceramics.

It is expected that this study will help to improve the knowledge about the Turgutlu clay and contribute to correct assessment of the deposits.

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