

Effect of Red Mud Addition on Mechanical and Physical Properties of Roof Tile

Sabriye. Pişkin, Aysel. Kantürk Figen, Emrah. Özkan, and Ünal. Özçay

Abstract—In this study, effect of red mud addition on mechanical and physical properties of roof tile were investigated. Three different amount of red mud (2%, 4% and 6%) mixed with standard tile clay which used in industrial application and prepared samples are fired to 900 °C, 940 °C, 980 °C and 1020 °C. Dry shrinkage, total shrinkage, loss of ignition, dry strength, compressive strength, water absorption and specific gravity tests performed to these samples and mechanical-physical properties were determined. Dry shrinkage values of samples decreased with increasing red mud content. Least shrinkages were observed at samples which have 6% red mud content. When obtained results were analyzed all of them shown that red mud contributed to properties of roof tile. Also, the use of this waste material in roof tile could provide a beneficial for environment.

Keywords—Red mud, roof tile, mechanical, physical, reused

I. INTRODUCTION

BAUXITE resources are estimated to be 55 to 75 billion tonnes, located in Africa (33%), Oceania (24%), South America and Caribbean Islands (22%), Asia (15%), and elsewhere (6%) [1]. Aluminum industries generate large quantities of highly polluting waste as a red mud. Red mud is highly alkaline (pH:10-13) and is composed primarily of alkalis, iron oxides and hydroxides, aluminium hydroxides, calcium carbonate, titanium, and silica [2,3]. The chemical and mineralogical compositions of red muds all over the world are widely different depending on the sources of bauxite, the technological process (Bayer process or Bauxite-Calcination method) and storing ages [4]. However, as a main constitute, iron oxide is generally occurring in red mud, and it is distributed in mineral phases of hematite (Fe_2O_3) or/and goethite (FeOOH). These iron phases mainly control the color and settling properties of red muds [5].

Annual worldwide production has been estimated at 70 million tons [6] and in Turkey, about 500000 m³ of strongly alkaline red mud-water pulp is dumped annually into special

constructed dams around Seydisehir Aluminum Plant as production proceeds [7].

Therefore, red mud disposal and recycling process became very important environmental project. Fig. 1 presents the current potential applications of red mud. However, none of those applications has been economically applied on an industrial scale [8].

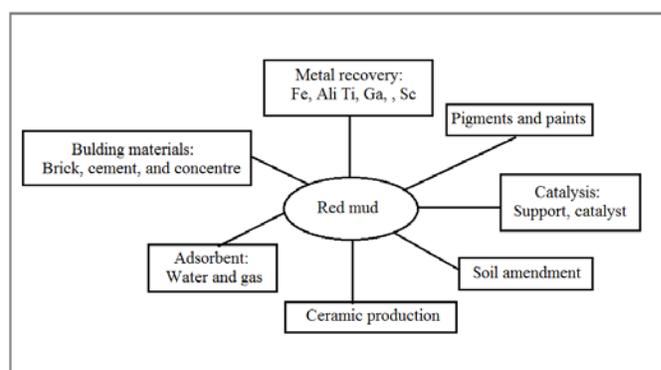


Fig. 1 Potential applications of red mud [8]

The utilization of the red mud in the different industries such as brick coloring [9], building material additive [10], ceramic production [11], production of Portland cement clinker [12], preparation of clay liners [13]. In addition all of these, also studies were carried out about red mud as iron recover, development of unsintered construction materials and pozzolanic pigment from red mud [14], [15], [16].

From the economic and environmental points of view, utilization of mixture red mud in the roof tile industry has proved to be highly efficient because of the resulting reduction in production cost, energy saving, and waste utilization.

In this study, manufacturing of roof tiles bearing mixture of red mud was investigated. Sahinkoy clay was mixed with Seydişehir red mud to prepare the roof tiles formulation. The drying shrinkage, total shrinkage, loss of ignition, dry strength, compressive strength, water absorption and specific gravity tests performed to these samples and mechanical-physical property was determined.

II. MATERIALS AND METHOD

A. Raw Materials

The clay material taken from Sahinkoy, east Ege region and the red mud material provided from the ETIBANK Aluminum Production Plant, Seydisehir, Turkey. Chemical compositions

Sabriye. Pişkin Department of Chemical Engineering, Yıldız Technical University, Istanbul 34210, Turkey, (corresponding author's phone:+902123834729 ; fax: +902123834744; e-mail: piskin@yildiz.edu.tr; sabriyepiskin@gmail.com).

Aysel.Kantürk Figen, Department of Chemical Engineering, Yıldız Technical University, Istanbul 34210, Turkey, (e-mail:akanturk@yildiz.edu.tr; ayselkanturk@gmail.com).

Emrah. Özkan, Department of Chemical Engineering, Yıldız Technical University, Istanbul 34210, Turkey, (e-mail:emrahozkan@gmail.com).

Ünal.Özçay, Gürallar tile factory, Kutahya, Turkey. (e-mail:unalozcay@hotmail.com).

of raw materials are given in Table I.

TABLE I
CHEMICAL COMPOSITION OF RAW

Components	Sahinkoy clay	Red mud
SiO ₂	59.71	15.58
Al ₂ O ₃	19.22	18.99
Fe ₂ O ₃	6.56	38.72
K ₂ O	3.12	0.22
CaO	2.02	4.26
MgO	1.07	0.08
TiO ₂	0.98	4.95
Na ₂ O	0.44	9.95
SO ₃	0.15	0.31
LOI (1000°C)	8.53	17.62

Raw materials were sieved to determination of average particle sizes, mass fractions, and mean diameter were calculated by Eq. 1-3 (TABLE II).

$$D_{p_{oi}} = (D_{p_i} + D_{p_{i-1}}) / 2 \quad (1)$$

$$\Delta\phi_i = M_i / M_{tot} \quad (2)$$

$$D_{p_{as}} = D_{p_{oi}} \times \Delta\phi_i \quad (3)$$

D_{p_i}: The biggest particle size in the sieve (µm), D_{p_{i-1}}: The smallest particle size in the sieve (µm), M_i: Amount of material on the sieve (g), M_{tot}: Total amount of grated material (g).

TABLE II
AVERAGE PARTICLE SIZES, MASS FRACTIONS VE MEAN DIAMETER OF MATERIALS

Sahinkoy clay			
Size (µm)	+63 -150	+150-250	+250 -841
D _{p_{oi}} (µm)	107.00	200.50	546.00
Δφ _i (wt.)	0.19	0.14	0.31
D _{p_{as}} (µm)	20.93	28.81	170.78
Red mud			
Size (µm)	+63 -150	+150 -250	+250 -841
D _{p_{oi}} (µm)	107.00	200.50	546.00
Δφ _i (wt.)	0.16	0.15	0.44
D _{p_{as}} (µm)	18.11	30.09	242.15

B. Dry Shrinkage (DS)

Lengths of shaped roof tiles were measured before (L_Y, cm) and after (L_K,cm) dried at 105°C and DS % were calculated by Eq. 4. Each DS were the average value of four parallel samples.

$$DS\% = \frac{L_Y - L_K}{L_Y} \times 100 \quad (4)$$

C. Total Shrinkage (TS)

Length of shaped roof tiles were measured before dried at 105°C and after fired at 900°C, 940°C, 980°C, 1020°C and TS % were calculated by Eq. 5. At least four samples of each mixture were prepared for TS tests.

$$TS\% = \frac{L_Y - L}{L_Y} \times 100 \quad (5)$$

D. Loss of Ignition (LOI)

LOI % of roof tile which were fired at 900°C, 940°C, 980°C and 1020°C, were calculated by the usage of before weight (A_k,g) and after (A_p, g) fired weight in Eq. 6. Each LOI was the average value of four parallel samples.

$$LOI\% = \frac{A_k - A_p}{A_k} \times 100 \quad (6)$$

E. Water Absorption (WA)

First of all weight of fired samples (S_{ka}, g) were obtained and then samples were put into boiling distilled water. Samples were put out after two hours and their weight (S_{ya}, g) were obtained. WA % of roof tiles was calculated by Eq. 7 as follow:

$$WA\% = \frac{S_{ya} - S_{ka}}{S_{ka}} \times 100 \quad (7)$$

Each WA was the average value of two parallel samples. Also a conversion factor was performed to these values to changing to factory conditions.

F. Specific Gravity (SG)

Weights of fired samples were obtained. Then samples were put into measuring cup and change of water volume (ΔV, cm³) indicated. Specific gravities of samples were calculated by Eq. 8. At least two samples of each mixture were prepared for SG tests.

$$SG = \frac{S_{ka}}{\Delta V} \quad (8)$$

G. Compressive Strength (CS)

Dry and fired samples were broken by device and results (P (kg)) which were obtained were used to obtained CS % by Eq. 9. L (cm) is buttress spacing, the b (cm) is width of sample and h (cm) is thickness of sample. Each values of CS were the average value of two parallel samples.

$$CS\% = \frac{3 \times P \times L}{2 \times b \times h^2} \times 100 \quad (9)$$

III. PREPARATION OF ROOF TILE

First of all sieving to 841 μ m was performed to raw materials and -841 μ m particle sizes were used. The amounts of red mud used in the mixtures were 2%, 4%, and 6%. Also red mud free samples were made to compare results of experiments. Preparation steps of roof tile are given in Fig.2.

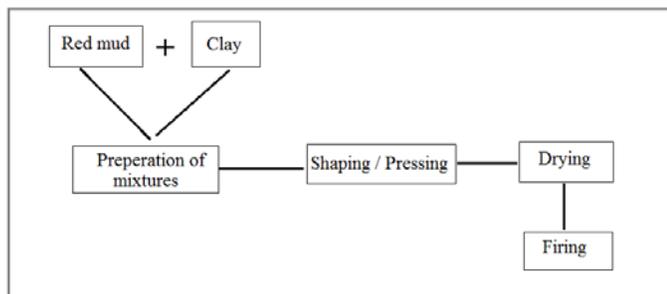


Fig. 2 Preparation of roof tile

The water content in the mixtures was controlled at approximately 18.5%. Samples with dimensions of 8 cm x 4 cm x 1.5 cm were made by pressing in a press machine at a pressure of 10 MPa. After samples were dried for one day at 40 °C and one day 105 °C in drying oven samples were fired to 900°C, 940°C, 980°C and 1020°C (Fig.3).

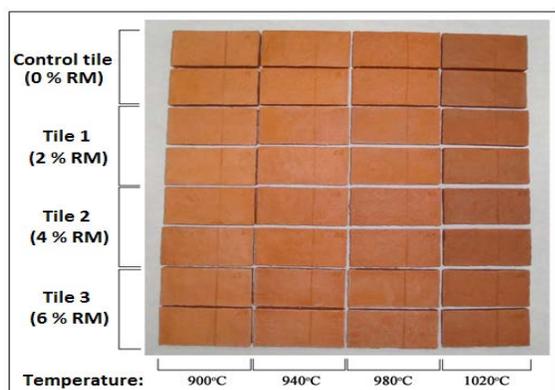


Fig. 3 Photos of produced roof tile containing red mud

IV. RESULTS AND DISCUSSION

Prepared samples were tested for dry shrinkage. Dry shrinkage was the average value of four parallel samples. The obtained results are shown in Fig. 4. The samples which contained red mud showed lower dry shrinkage.

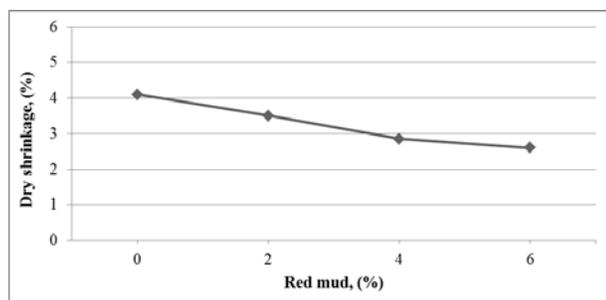


Fig. 4. Results of dry shrinkage tests

Prepared samples which fired at 900 °C, 940 °C, 980 °C and 1020°C were tested for total shrinkage. Total shrinkage was the average value of four parallel samples. The obtained results are shown in Fig. 5. The samples which contained red mud showed lower total shrinkage for each fired temperature.

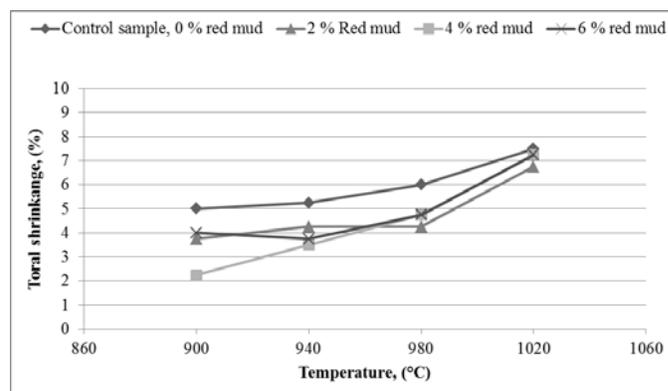


Fig. 5 Results of total shrinkage tests

Prepared samples which fired at 900, 940, 980 and 1020°C were tested for loss of ignition. The obtained results are shown in TABLE III. When these results were analyzed, obtained that standard tile mixture showed lower loss of ignition.

TABLE III
LOSS OF IGNITION OF TILE (%)

Temperature (°C)	RM (%)			
	0	2	4	6
900	5.53	5.14	5.17	5.18
940	5.51	5.19	5.16	5.23
980	5.26	5.29	5.32	5.53
1020	5.26	5.39	5.28	5.62

Prepared samples were tested for water absorption. The amount of water absorption of standard tile samples and samples which including 2%, 4% and 6% red mud, showed in Fig. 6. The samples which contained RM showed lower water absorption for each fired temperature especially at 1020°C.

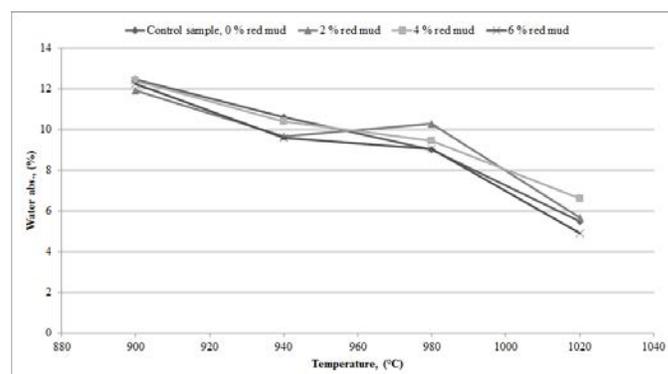


Fig. 6 Results of water absorption tests

Also, when a conversion factor was performed to these values to changing to factory conditions same results were obtained and these were showed in Fig 7.

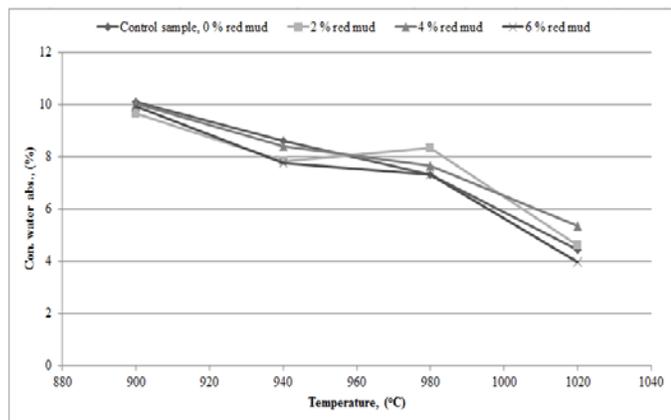


Fig.7 Converted water absorption values of samples

Prepared samples which fired at 900, 940, 980 and 1020°C were tested for specific gravity. The obtained results are shown in TABLE IV. When these results were analyzed, obtained those specific gravity values of samples increased with increasing fired temperature and red mud content.

TABLE IV
SPECIFIC GRAVITY OF TILE

Temperature (°C)	Red mud (%)			
	0	2	4	6
900	1.62	1.63	1.46	2.06
940	1.57	1.56	1.87	2.07
980	1.77	1.90	1.81	2.54
1020	1.98	2.10	2.01	3.16
Commercial tile	3.02			

Influence of red mud content on compressive strength was investigated by dry samples and results were given in Fig. 8. The results show that compressive strength values of samples increased with increasing red mud content.

Influence of red mud content and firing temperature on compressive strength were investigated and obtaining results were shown in TABLE V. Compressive strength increased with the increasing of red mud content and firing temperature. These results show that the influence of red mud and firing temperature on compressive strength are positive.

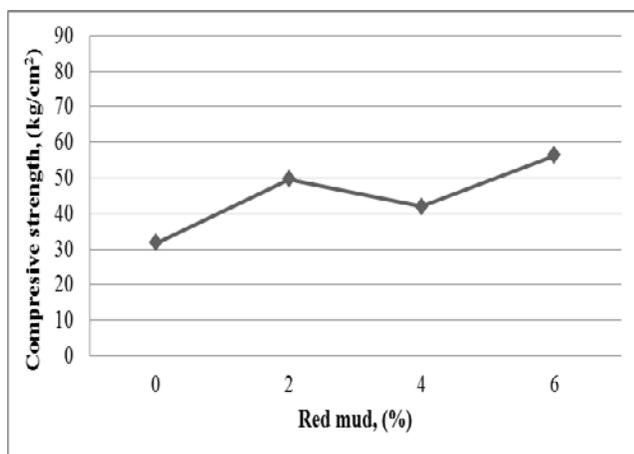


Fig. 8 Results of compressive strength tests of dried samples

TABLE V
COMPRESSIVE STRENGTH OF TILE

Temperature (°C)	Red mud (%)			
	0	2	4	6
900	71.90	111.10	96.70	171.80
940	115.10	133.95	93.10	150.00
980	123.50	132.50	105.11	181.10
1020	129.30	139.25	150.70	187.50

Also, when a conversion factor was performed to these values to changing to factory conditions same results were obtained and these were showed in Table VI. Almost all samples reaches Turkish criterion of the tile. Firing strength value of commercial roof tile should be minimum 122 kg/m² according to the TSE EN 1304. Even samples which contain 6% red mud and firing at 1020°C reaches 244.70 kg/cm².

TABLE VI
CONVERTED COMPRESSIVE STRENGTH OF TILE

Temperature (°C)	Red mud (%)			
	0	2	4	6
900	93.80	145.00	126.20	224.20
940	150.20	174.80	121.40	195.70
980	161.20	172.90	137.50	236.30
1020	168.80	181.70	196.70	244.70

V. CONCLUSION

The results of this work point out the possibility of using red mud as raw material for roof tile. Physical and mechanic tests were performed to investigate of red mud addition on the physical and mechanic characteristics of roof tile samples. More specifically the sample with red mud presented the following characteristics:

- Dry shrinkage values of samples decreased with increasing red mud content. Least shrinkages were observed at samples which have 6% red mud content.
- Total shrinkage values of samples decreased with increasing red mud content. Also observed that total shrinkage increased with the increasing firing temperature.
- Loss of ignition increased with the increasing of red mud content and firing temperature.
- Water absorption of samples decreased with increasing red mud content and firing temperature.
- Specific gravity of samples increased with increasing fired temperature and red mud content.
- Compressive strength values of dry samples increased with increasing red mud content.
- Compressive strength values of fired samples increased with the increasing of red mud content and firing temperature.

When obtained results were analyzed all of them shown that red mud contributed to properties of roof tile. Also, the use of this waste material in roof tile could provide a beneficial for environment.

REFERENCES

- [1] H. S. Altundogan, F. Tumen, M. Bildik, "Arsenic removal by red mud",

- Waste Manag, 2000, vol. 20, pp.761–767.
- [2] N.W.Menzies, I.M.Fulton, W.J. Morrel, “Seawater neutralization of alkaline bauxite residue and implications for revegetation”, *J Environ Qual*, 2004, vol.33, pp.1877–1884.
- [3] J.Pera, R.Bouzama, J.Ambroise, “Development of pozzolanic pigment from red mud”, *Cem Concr Res*, 1997, vol.27(10), pp.1513–1522.
- [4] X.Liu, N.Zahang, H.Sun, J.Zhang, L. Li, “Structural investigation relating to the cementitious activity of bauxite residue Red mud”, *Cement and Concrete Research*, 2011, vol, 41, pp 847–853.
- [5] L.Y. Li, “A study of iron mineral transformation to reduce red mud tailings”, *Waste. Manage*, 2001, vol. 21, pp.525–534.
- [6] S. Kumar S, R. Kumar R, A. Bandopadhyay, “Innovative methodologies for the utilization of wastes form metallurgical and allied industries”, *Resour Conserv Recycling*, 2006, vol.48, pp.301–314.
- [7] T. Kavas, “Use of boron waste as a fluxing agent in production of red mud Brick”, *Building and Env.*, 2006, vol.41, pp. 1779-1783.
- [8] S. Wang, H.M. Ang, M.O. Tadó, “Novel Applications of Red Mud as Coagulant, Adsorbent and Catalyst for Environmentally Bening Processes”, *Chemosphere*, 2008, vol. 72, pp. 1621-1635.
- [9] M. P. Kolesnikova, “The use of red mud for brick coloring”, *Glass and Ceramics*, 1998, vol. 55, pp. 3-4.
- [10] J. Somlai, V. Jobbágy, J. Kovács, S. Tarján, T. Kovács, Radiological aspects of the usability of red mud as building material additive, *Journal of Hazardous Materials*, 2008, vol. 150, pp. 541-545.
- [11] A. Akinci, R. Artir, Characterization of trace elements and radionuclides and their risk assessment in red mud, *Materials Characterization*, 2008, vol. 59, pp. 417-421.
- [12] P. E. Tsakiridis, S. Agatzini-Leonardou, P. Oustadakis, “Red mud addition in the raw meal for the production of Portland cement clinker”, *Journal of Hazardous Materials*, 2004, vol. 116, pp. 103-110.
- [13] E. Kalkan, “Utilization of red mud as a stabilization material for the preparation of clay liners”, *Engineering Geology*, 2006, vol. 87, pp. 220-229.
- [14] W. Liu, J. Yang, B. Xiao, “Application of Bayer red mud for iron recovery and building material production from aluminosilicate residues”, *Journal of Hazardous Materials*, 2009, vol. 161, pp. 474-478.
- [15] J. Yang, B. Xiao, “Development of unsintered construction materials from red mud wastes produced in the sintering alumina process”, *Construction and Building Materials*, 2008, vol. 22, pp. 2299-2307.
- [16] J. Pera, R. Boumaza, J. Ambroise, “Development of a pozzolanic pigment from red mud, *Cement and Concrete Research*”, 1997, vol. 27, pp. 1513-1522.