

USABILITY OF BORAX TAILINGS IN BUILDING BRICKS AS AN ADDITIVE

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TUNCAY USLU

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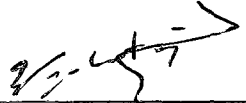
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Prof. Dr. Tayfur ÖZTÜRK
Director

I certify that this thesis satisfies all the requirements as a thesis for the degree of Master of Science in Mining Engineering.


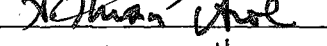
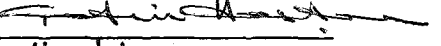
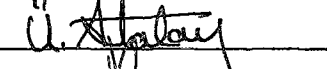
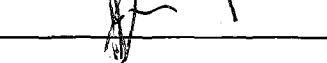

Prof. Dr. A. Günhan PAŞAMEHMETOĞLU
Chairman of the Department

This is the certify that we have read this thesis and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.


Assoc. Prof. Dr. Ali İhsan AROL
Supervisor

Examining Committee Members

Prof. Dr. Gülhan ÖZBAYOĞLU(Chairman)
Assoc. Prof. Dr. Ali İhsan AROL (Supervisor)
Prof. Dr. Çetin HOŞTEN
Prof. Dr. Ümit ATALAY
Assoc. Prof. Dr. Salih ERSAYIN

ABSTRACT

USABILITY OF BORAX TAILINGS IN BUILDING BRICKS AS AN ADDITIVE

USLU, Tuncay

M.S., Department of Mining Engineering

Supervisor: Assoc. Prof. Dr. Ali İhsan AROL

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This research is concerned with the determining the possibility of the use of Etibank Kırka Borax Works tailings in building bricks as an additive due to flux role of borax and similarity between these tailings and ordinary brick clays with respect to their chemical components.

For this purpose, five kinds of bricks containing 10 %, 20 %, 30 %, 40 % and 100 % tailings material, bricks containing the same percentage calcined tailings material, and bricks containing only ordinary brick clay were fired at 700°C, 800°C, and 900°C and strength tests were carried out on the fired bricks. The brick groups showing the highest strength were subjected to other brick tests.

At the end of the study it was determined that that it would be possible to manufacture building bricks of sufficient qualities at lower temperatures with cost saving by using the tailings of Kırka Borax Works as additive. Moreover, bricks with tailings addition fired at 900 °C were found to have better qualities than bricks with no tailings addition.

Keywords: Building Brick, Borax, Waste Utilization

ÖZ

BORAX ATIKLARININ İNŞAAT TUĞLASINDA KATKI OLARAK KULLANILABİLİRLİĞİ

Tuncay USLU

Yüksek Lisans, Maden Mühendisliği

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Bu çalışma Etibank Kırka Borax İşletmesi atıklarının boraksın flaks rolü ve atıklar ile tuğla killerinin kimyasal bileşen bakımından benzerliği sebebiyle inşaat tuğlası yapımında kullanılabilme olasılığının belirlenmesi ile ilgilidir.

Bu amaçla sırasıyla % 10, % 20, % 30 % 40 ve 100% atık malzeme içeren beş tip tuğla gurubu, aynı oranlarda ve kalsine edilmiş atık malzeme içeren beş tip tuğla gurubu ve sadece normal tuğla kili içeren tuğla gurubu 700°C, 800°C ve 900°C' de pişirilmiştir ve pişirilen tuğlalar üzerinde dayanım testleri yapılmıştır. En yüksek dayanımı gösteren tuğlalar diğer tuğla testlerine tabi tutulmuşlardır.

Çalışma sonunda Kırka Borax İşletmesi atıklarının katkı olarak kullanılmasıyla yeterli kalitede inşaat tuğlasının daha düşük sıcaklıklarda ve daha az maliyetle üretilmesinin mümkün olabileceği belirlenmiştir. Ayrıca, 900 °C de pişirilen atık katkılı tuğlaların atık içermeyen tuğlalardan daha kaliteli oldukları bulunmuştur.

Anahtar Kelimeler: İnşaat Tuğlası, Boraks, Atık Değerlendirme

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CHAPTER 1

INTRODUCTION

Turkey has the largest known reserves of boron minerals in the world[1]. Boron is mined from four major areas at Kırka, Emet, Bigadiç, Kestelek. The borate deposits consist of colemanite, tincal and ulexite. Both surface and underground mining methods are utilized for production. All of the mines are state-owned and managed by the government corporation, Etibank[2]. The concentration processes consist of only hand sorting, scrubbing and classification. The tailings of the concentrators are clays containing considerable amount of B_2O_3 . For example, in Kırka Borax Works, the tailings contain 15.18 % B_2O_3 [3] and are sent to tailings ponds. This has been causing serious environmental pollution.

Recovery of boron minerals from these tailings has been studied on the laboratory scale by several researchers[4,5]. However, it does not seem probable that this material will be used as a source of boron in the near future. Therefore, direct use of the tailings without recovering boron minerals should be considered.

It is known that borax is a fluxing agent[6]. It combines with silica and alkalis to form a glassy structure and lowers the maturing temperature as well as strengthens the body[7]. In addition, montmorillonite is a dominant mineral in the tailings[8] as in the brick clays. That is, chemical components of the tailings are similar to that of brick clays. Thus, it might be a good idea to use the clayey waste material from boron mineral concentrators as a source of clay for brick manufacturing. By doing so, a lower firing temperature and/or a stronger brick production might be achieved.

In this study possible use of Kırka tailings in brick manufacture was investigated. For this purpose, tailings material taken from Kırka and brick clay taken from Kılıçođlu Brick Factory were mixed at certain ratios and 11 different brick groups were obtained, these were then fired at 3 different temperatures. The brick groups showing the highest strength were subjected to the other brick tests.

Possibility of use of Kırka tailing in brick manufacture has been investigated previously by Sönmez (1992) and Ediz (1994). In the former study, bricks with 20 %, 30 %, 40 %, 50 %, 60 % and 100 % tailings were fired at only usual building brick firing temperature (900°C)[9]. In the latter study, bricks with 80 %, 85 %, 90 %, 95 % and 100 % tailing were fired at 650°C, 700°C, 750°C and 800°C [10]. That is, the aim was to manufacture the bricks completely from the tailings. In addition, calcined tailings were not studied in either study. In this investigation, the tailings were used only as an additive in brick manufacturing and bricks with 10 %, 20 %, 30 %, 40 % and 100 % tailings were manufactured in this study. Calcined tailings were also used in the bricks.

CHAPTER 2

LITERATURE SURVEY

2.1. Bricks Manufacturing

2.1.1. Raw Materials

Basic raw materials are low-grade, coloured-firing clays. Non plastic substances are added in the form of sand, slag, fly-ash, etc. The proportions added are given by the required forming properties and behaviour on firing[11].

Building brick clays depend for their value on their physical properties rather than their chemical composition and, consequently, the permissible range of composition of a brick clay is very wide. The principal properties required in a clay for brickmaking purpose are that (a) it shall be present as a deposit sufficiently extensive and accessible to warrant large-scale development, (b) it shall be plastic enough to mould easily into shape and retain that shape in both wet and dry states, and (c) it shall vitrify sufficiently at a temperature of 950-1100°C to form hard bricks without excessive shrinkage or deformation[12].

The clays which satisfy these requirements are limited, and although there are many which can be used quite satisfactorily, it is wrong to assume that any deposit of clay can be used for making building bricks[12]. Clays used in manufacturing building bricks are generally montmorillonite, illite, chlorite type clays[13].

The clays used may contain 35-90 % of silica. (the average being about 65 %)[12]. Silica is not plastic and therefore reduces the plasticity of the clay; an excess

of silica destroys the cohesiveness of the clay. The principal positive attribute of silica is reduction of shrinkage[14].

Clays suitable for building bricks may contain up to 15 % of alkalis (Na_2O , K_2O) (the average being about 8 %), up to 15 % of calcium compounds expressed as lime (CaO) (the average being below 2 %), and up to 7 % magnesia (MgO) (the average being about 1 %)[12]. These basic oxides act as flux. By combining with the silica to form silicates, lower melting points result. Lime must be in a very finely divided state so that it will be completely hydrated or fluxed in the process of manufacture of the bricks. The presence of lumps of unhydrated lime which become hydrated after long periods is the cause of defects on brick walls[15].

Iron oxide (FeO) is the chief red coloring agent in the clay and occurs in proportions up to 32 % (the average being 3-8 %). It also acts as a flux and adds greatly to the hardness and strength of brick[13].

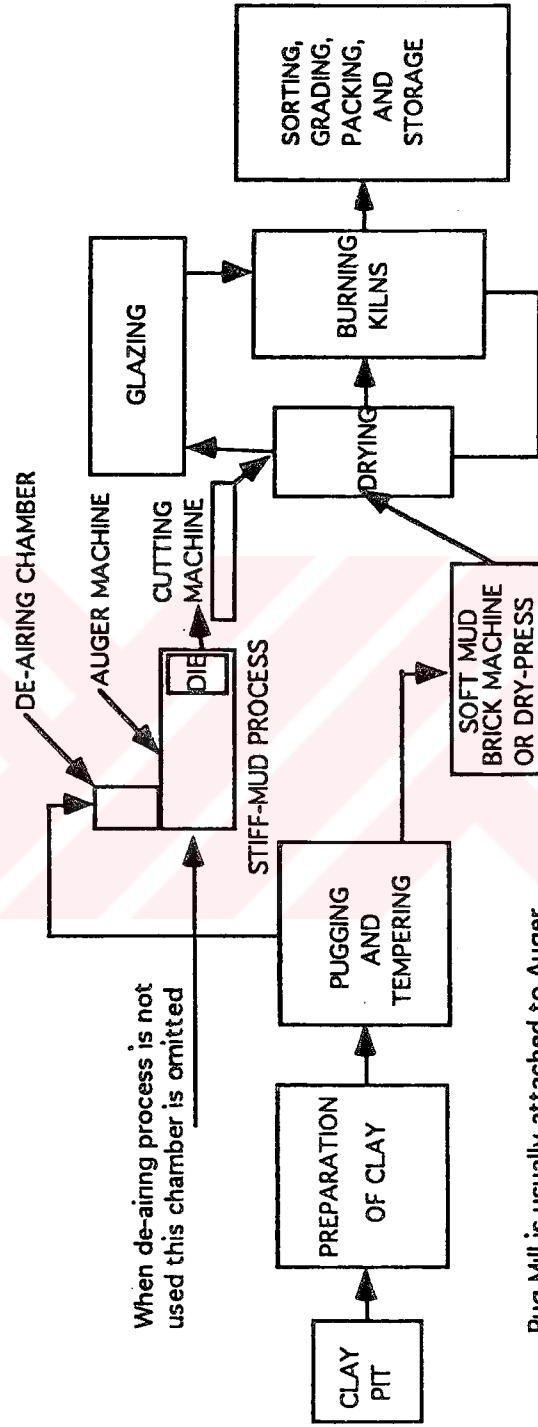
The metallic compounds most likely to cause trouble in the manufacture of building bricks are limestones and soluble salts. The limestones produce lime which may crack the bricks[12]. Soluble salts, as sulfates, carbonates, and other compounds (usually of Na, K, Mg, and Ca) result in efflorescence on the bricks[13].

The clay also should not contain pyrite which may be the cause of local defects due to excessive fusion[11]. Organic impurities are sometimes present in considerable quantities in the form of humus compounds, bitumen, etc. They give the clay a gray or dark-gray color and burn out during firing[13].

2.1.2. Manufacturing Stages

Process of brick manufacturing, schematically presented in Figure 1, may be divided into the following steps:

- Selection and "winning" of suitable clay, and storage.



When de-aring process is not used this chamber is omitted

Pug Mill is usually attached to Auger Machine or Soft-mud brick machine in up to date plants.

Figure 1: Stages of Brick Making Process [15]

- Preparation of clay, including cleaning, removing large pebbles, grinding and screening.
- Mixing and tempering to produce plasticity, uniformity, and homogeneity.
- Shaping into units by extruding machines and cutters, molds, presses, or other appliances.
- Drying, either by natural or artificial means.
- Firing, usually in kilns[15].

Winning : "Winning" is the term applied to obtaining the clay from the pit. Working of the pit involves two operation; stripping or removal of the overburden and extracting the clay. Scrapers, bulldozers, and excavators are used for stripping. Power shovels are used in excavating clay from pits. Many shales are so solidified that they have to be loosened by blasting[13,15].

Preparation of Clay : Although clay may sometimes be used with no preparation, it generally is subjected to treatment to improve its properties prior to forming it into the desired shape. These treatments improve the plasticity, drying, and firing properties of the clay.

Clay may require crushing or grinding as the first step in its preparation. This is true if it contains small stones or if it has been agglomerated into hard masses, such as shales[14]. For bricks the ground clay should be free from particles larger than No: 22 mesh, though for some common bricks as much as 10 percent of particles 0.125 in. in diameter may no harm[12].

After the preliminary steps of preparation, the clay is tempered, the object of which is to produce a homogeneous plastic mass. This is usually accomplished in a pug mill, which is a horizontal cylinder provided with one or two power-driven shafts with blades rigidly attached. The revolving blades slice up and thoroughly mix

the mass until it is ejected through an opening at one end. During the pugging operation, it may be necessary to add sand to reduce shrinkage, or more water to produce the desired plasticity[15].

The subjection of a plastic mass of clay to vacuum, so that adsorbed air is removed, greatly improves its working, drying, and firing properties. It has been established that the presence of air bubbles decreases plasticity. In molding clay, the air bubbles are flattened out, forming planes of weakness. Large volumes of air also cause trouble by thermal expansion during drying and firing. Deairing of clay is accomplished in a machine which consists of two pug mills with a vacuum chamber in between. The clay is extruded by the first pug mill into the vacuum chamber; the second mill discharges the de-aired clay[14].

Forming Methods : There are three process which are used in forming bricks. They are the "soft-mud", "stiff-mud", and "dry-press" processes[14].

The soft-mud process is an automation of the old technique of hand-molding bricks. In essence, it involves mixing a large enough amount of water with the clay to make it into a soft mud, which is then pressed into molds, by a plunger. In order to prevent the clay from sticking to the molds, they are usually sanded before filling[14].

The molds are tied together in a battery of 8 to 12 units. As the molds emerge from the machine, the excess clay is scraped off. Then, the gang molds are tipped over and tapped to release the bricks onto a waiting pallet. As the loaded pallet goes to a dryer rack, the empty molds move below the machine where they are washed with a water spray and resanded. They are then elevated into the machine ready to be filled again[16]. The advantages of this process are the high degree of homogeneity which is achieved through the use of relatively large amounts of water and the fact that the process is adaptable to a very wide variety of clays. Articles made by this process are free of laminations and other inhomogeneties, and are quite resistant to frost action. The principal disadvantage of this proces is the fact that a large amount of water must be removed in the drying operation[14].

The stiff-mud process is a relatively modern improvement over the older soft-mud process[14]. Machinery for extrusion is adaptable to automation and high speed production. Extrusion machines are available in several sizes. Some are capable of producing products at the rate of 150,000 standard bricks equivalents per day, and they require electric motors ranging from 75 H.P to 350 H.P.[16]. Only enough water is added to make it possible to extrude the stiff clay through a die, after which it is rigid enough to hold its shape without being in a mold. The decrease in the amount of water used results in shorter drying times and greater fuel economy. The extruded clay leaves the machine in a continuous ribbon, which is then cut to the desired length by means of a wire framework. The principal disadvantages of this process are that only a limited variety of clays suitable for this process, that is, those of medium plasticity, and that a laminated structure is obtained, since the clay passes through the center of the die at a higher velocity than at the edges[14].

In the dry-press process, an air-dried clay which is low in moisture is used. The clay is mechanically pressed in a mold in the dry-press machine by a reciprocating charger located below the hopper. At each revolution of the machine charger moves forward, and when it is directly over the molds the bottom plunger in the molds descends, allowing the molds to be filled with clay. The charger is withdrawn, the clay supply is shut off, and then the top and bottom plungers move toward each other in the molds, compressing the clay between them. The pressure is now relieved and then applied a second time, the compression of the clay being greater than at first and ranging from 550 to 1500 pounds per square inch. The upper plunger is now withdrawn, and the bottom plunger raises the bricks to the level of the top of the mold. The next stroke of the plunger pushes the finished brick upon the mold table, whence it is removed to the dryers[15].

Drying : After the bricks have been formed excess moisture must be removed by drying before firing, otherwise the high temperature in the kiln would cause warping or cracking due to shrinkage stresses. In order for moisture to be removed from clay, it must first diffuse through to the material to the surface, and then it must evaporate from the surface. Diffusion requires the existence of a moisture gradient. Thus the surface tends to dry faster than the interior, particularly if the drying rate is

rapid or if the material is thick. In order to avoid warping or surface cracking it is necessary to keep the drying rate low[14].

In practice the duration of the drying, depending on the properties of the mixture, the drying conditions, and the design of the dryer, varies between 10 hours and two or more days for artificial drying, and is as long as 15-20 days for natural drying[13]. The temperature required is from 38°C to 149°C [15].

The most common types of equipment for drying include stationary dryers and tunnel dryers. Stationary dryers, called "hot-floor" dryers are essentially oversize hot plates like those used in the laboratory. They are heated from below by direct fires, by hot products of combustion from kilns, or by steam. The use of steam is preferable, since it simplifies temperature control. In tunnel dryers, the bricks are loaded on cars which are gradually pushed through a heated tunnel. The tunnels are usually built of masonry and may be 100 feet or more in length. As a car enters at the end, another leaves at the discharge end. Excellent control of the temperature, humidity, and air circulation are possible with this type of dryer. It is also well adapted for high production rates. Its chief disadvantage is its high initial cost[14,15].

Firing : The firing of bricks in a kiln requires an average time of 3 to 4 days, after which the openings are tightly closed and the kiln is allowed to cool very slowly. The process of firing may be conveniently divided into the following stages:

Water Smoking: During this period which requires about 12 hours the free water in the clay is driven off under temperatures ranging from 125°C to 175°C.

Dehydration: Dehydration consists of expelling chemically combined water by breaking down the clay molecules. It begins at about 425°C and is completed at about 750°C.

Oxidation: Oxidation begins during the dehydration stage. All combustible matter is consumed, carbon is eliminated, the fluxing materials are changed to oxides, and sulfur is removed.

Vitrification: During this stage the minerals fuse to form glasses, which upon cooling bond the unvitrified particles together[14]. Liquid formation commences at the temperature of the lowest eutectic point of the components in the mixture; then, with progressively increasing temperature, the amount of liquid phase increases rapidly. Alkali-bearing minerals or clays with a high content of alkalis begin to fuse at low temperatures[12]. The eutectic temperatures for many of the common impurities in clay, when associated with alumina and silica are shown in Table 1.

Table 1: Fusion Temperatures of Fluxes in Association with Alumina and Silica[12]

Oxide	Lowest Eutectic Temperature°C
Na ₂ O	732
K ₂ O	695
CaO	1170
Fe ₂ O ₃	1073
MgO	1345

In building bricks complete vitrification is unnecessary and they are fired at about 900°C - 1000°C, at which only just sufficiently vitrified matter is present to surround the particles and unite them strongly together[12].

The firing process is conducted in kilns of two types, intermittend and continuous kilns. Intermittend kilns may be further subdivided into up-draft and down-draft kilns.

The up-draft kilns have a permanent sides made of brick masonry 12 to 16 inches thick, and the heat is generated in ovens outside. The flames and hot gases enter the kiln through fire passages in the walls.

The down-draft kilns require permanent walls and a tight roof. The floor has openings connecting with flues leading to a stack. Most down-draft kilns are built in a circular or beehive shape, but some are rectangular. Heat is generated in outside ovens, and the flames and gases enter the kiln through vertical flues carried to about half the height of the kiln. The heat therefore enters the brickwork at the top and is drawn downward by the chimney draft to the flues below the floor, and thence to the chimney or stack. The down-draft kiln has a much higher efficiency than the up-draft kiln and give a more uniform temperature[15].

The most recent types of kilns are continuous kilns. They possess the virtue of utilizing the heat in the gases leaving the hot firing zone for preheating the bricks up to the temperature. This is accomplished by counterflow of bricks and gaseous products of combustion. In the chamber type kiln, counterflow is achieved by moving the gases through a series of chambers in a circle, each chamber being operated in an intermittent manner. The newer method is to move the wares on cars through a tunnel, countercurrent to the gases. This is truly a continuous firing process. The tunnel may be circular, instead of straight, in which case the wares are placed on a large horizontal ring which turns slowly through the kiln. Although continuous kilns are high in initial cost, they are economical of fuel, and the results are more uniform than is obtained with intermittent kilns[14].

2.2. Boron and Boron Minerals

2.2.1. Boron and Principal Boron Minerals

Boron, the fifth element in the periodic table, is the only electron-deficient non metallic element. It has a great affinity for oxygen. In nature boron always occurs in the oxygenated state, mainly as borates. The structure of these covalently bonded boron-oxygen compounds consists of either planer BO_3 units with 120° between bonds or tetrahedral BO_4 units. In addition boron is the only light element having two abundant isotopes. ^{10}B (18.8 %) and ^{11}B (81.2 %).

Table 2 : The Principal Boron Minerals and Their Compositions[18]

MINERALS	COMPOSITION	WEIGHT% B_2O_3
SASSOLITE	$B(OH)_3$	56.4
BORAX(TINCAL)	$Na_2O.2B_2O_3.10H_2O$	36.5
TINCALCONITE	$Na_2O.2B_2O_3.5H_2O$	47.8
KERNITE	$Na_2O.2B_2O_3.4H_2O$	51.0
INYOITE	$2CaO.3B_2O_3.13H_2O$	37.6
MEYERHOFFERITE	$2CaO.3B_2O_3.7H_2O$	46.7
COLEMANITE	$2CaO.3B_2O_3.5H_2O$	50.8
PRICEITE	$4CaO.5B_2O_3.7H_2O$	49.8
ULEXITE	$Na_2O.2CaO.5B_2O_3.16H_2O$	43.0
PROBERTITE	$Na_2O.2CaO.5B_2O_3.10H_2O$	49.6
HYDROBORACITE	$CaO.MgO.3B_2O_3.6H_2O$	50.5
INDERITE	$2MgO.3B_2O_3.15H_2O$	37.3
SZAIBELYITE	$2MgO.B_2O_3.H_2O$	41.4

Boron is found in the earth's crust at an average concentration of about 10 ppm. Large deposits of commercially valuable boron minerals are only found in a few localities, usually sites of earlier intense volcanic activity. There are about 150 known boron-containing minerals, and of these only tincal, colemanite, ulexite, kernite, probertite, and szaibelyite are of significant commercial importance[17]. The principal boron minerals and their compositions are listed in Table 2.

2.2.2. Reserves

Boron minerals occur in the few locations in the world where ideal combinations of boron source, generally of volcanic origin, topography, and climate interacted at propitious in geological history. Present estimates of boron mineral reserves are 1 billion tons of ore. Reduced to a contained-boron oxide base, world reserves are on the order of 355 million tons, as indicated in Table 3. World resources of boron minerals including hypothetical resources, are estimated to be two times greater than the reserve base.

Table 3: World Boron Reserves and Reserve Base[19].
(Million short tons of boron oxide)

	Reserves	Reserve base ¹
North America: United States.....	115	230
South America.....	30	100
Europe.....	150	150
Asia		
China.....	30	40
Turkey.....	120	160
Total.....	150	200
World Total.....	355	680

¹The reserve base includes demonstrated resources that are currently economic (reserve), marginally economic (marginal reserve), and some of those that are currently subeconomic (subeconomic resource)

Turkish reserves of boron minerals appear to be greater than those of United States. Calcium borate reserves in the Emet district of Kütahya Province are contained in three colemanite deposits at Killik, Espiye, and Hisarcık. Reserves are 13 million tons of colemanite ore containing 37 % to 42 % boron oxide with up to 3,500 parts per million arsenic. Sodium borate reserves in the Kırka district of Eskişehir Province are approximately 400 million tons of borax ore containing 26 % to 27 % boron oxide. In the Bigadiç area, colemanite reserves are 10 million tons of ore, and ulxite-probertite reserves are 12 million tons of ore containing 36 % to 38 % boron oxide. Colemanite reserves in the Mustafa Kemalpaşa district are 2 million tons of ore containing 40 % boron oxide.

U.S. reserves of boron minerals are concentrated in the Mojave Desert of California. All inclusive estimates of U.S. reserve base are 230 million tons of boron oxide. Reserves of sodium borate ores in the Kramer deposit at Boron (Kern County) reportedly are 140 million tons of approximately 25 % B_2O_3 ore. The deposit also contains subeconomic grades of calcium and sodium-calcium borates. In San Bernardino County, the brines of Searles Lake have been estimated to contain 40 million tons of sodium borate of which about 11 million tons of boron oxide are recoverable. Two low grade deposits of calcium borate, colomanite, occur near Kramer Junction in western San Bernardino County. These deposits have been estimated to contain a total of 100 million tons of 6 % B_2O_3 content. Inyo County reserves of calcium and sodium-calcium borates in the Death Valley area approach 20 million tons ore having +20 % B_2O_3 content, and the total resource is estimated at 45 million tons of ore. Other U.S. reserves include a low-grade colemanite deposit in Clark County, NV, the waters of the Great Salt Lake, UT, which analyze 20 to 35 parts per million boron, and in the Owens River, CA, an average 230 tons per year of boron is discharged.

Reserves in the Commonwealth of Independent States, primarily magnesium borates, szaibelyite, are about one-half as those of the United States. Several dozen deposits have been discovered in the Inder district, 150 miles north of the Caspian Sea in Kazakhstan, in Caucasus, and near Lake Baikal.

South central and northeastern China, and northern Tibet, possess playa lakes that yield moderate supplies of borates. Chaerhan Lake, a 2,000 square mile lake in the Qaidam basin in Qinghai Province, contains boron, lithium, and potash. Borate reserves are also located in the Ladakh district of northern India.

In Argentina, reserves at the Tincalayu deposit are 2.5 million tons with resources of 5 million tons. In Bolivia, deposits in the Altiplano region contain 8 million tons of resources. Reserves at Salar de Uyuni, are estimated at 3.5 million tons. In Chile, reserves of several deposits are estimated at 20 million tons. Reserves at Laguna Salinas, Peru, are 11 million tons.

In Europe, small quantities of natural boric acid, sassolite, occur in Italy, and some magnesium borates, boracite, occur in Germany[19].

2.2.3. Uses

Boron ores are produced into a variety of boron chemicals such as borax and boric acid. Approximately 50 % of boron consumption is used in various glasses because of the ability of the boron to lower the melting temperature and produce a less viscous glass at a lower temperature. The second largest use is in soaps and detergents. Other uses include agricultural where boron is one of 6 micronutrients and 16 nutrients essential for plant growth, and as fire retardants, primarily in cellulose insulating. Small amounts go into nuclear and metallurgy uses. Non-sodium borates such as colemanite and boric acid are used in borosilicate glass that requires low sodium, such as "E" glass used in textile grade fibreglass for reinforcement. Ulexite, which contains some sodium, can be used in insulation grade fibreglass. Many of glass uses prefer anhydrous borax because of the reduced water that results in steam when added to a furnace. Borax is also used for enamels, frits, and glazes. Borax decahydrate is used in various enamels, and cleaners. Borax pentahydrate is used in fibreglass insulation, borosilicate glass, textile glass fibres, enamels, cleaners, agriculture, metallurgy and fire retardants. Anhydrous borax is used in glass and enamels. Boric acid is used in fibreglass, glasses, textile glass, and

fire retardants. Ulexite is often used in agriculture because it can be added in a dry form and dissolves slowly[20]. Production and main uses of boron minerals and compounds are illustrated in Figure 2 and Figure 3.

2.3. Kırka Borax Works

Of all boron plants in Turkey Etibank Kırka Borax Works is the only establishment which has a mine, concentrator, and refining plant. Kırka borax deposit, located about 60 km south of the city of Eskişehir was discovered in 1960, and is the biggest borax deposit in the world. Initial work concentrated on the near surface colemanite, but later drilling disclosed sizable thicknesses of borax and this is now being brought into open pit production by utilizing modern truck-shovel methods[1].

Concentration plant was found in 1975 to process 600,000 tons of ore assaying about 24-26 % B_2O_3 and to produce a concentrate assaying about 34.5 % B_2O_3 [12]. Ore transported from the open pit is dumped into a silo on which a grizzly with 400 mm aperture is placed. The ore is scrubbed by using 6 tanks in the first plant and 12 tanks in the second plant after being crushed to -6 mm by three subsequent screening and crushing circuits. Then clay is removed by screening, cycloning, and mechanic classification and grainy material is recovered as concentrate by centrifuging. Flowsheet of Kırka Concentrator is presented in Figure 4[21].

In 1984 refining plant was constructed to produce 160,000 tons of borax pentahydrate and 17,000 tons of anhydrous borax from this concentrate. Production in refining plant is based on crystallization following the dissolving at 98°C. Dissolved ore is separated from the undissolved gangue and solution is passed through two different crystallizers. Pentahydrate and decahydrate crystallize. Dried crystals are screened and sold in a specified particle size range. Anhydrous borax is produced by dehydrating the undersize of decahydrate and pentahydrate screens, in a furnace and this product is sold following the crushing and screening. Flowsheet of Kırka Refining Plant is presented in Figure 5 [21].

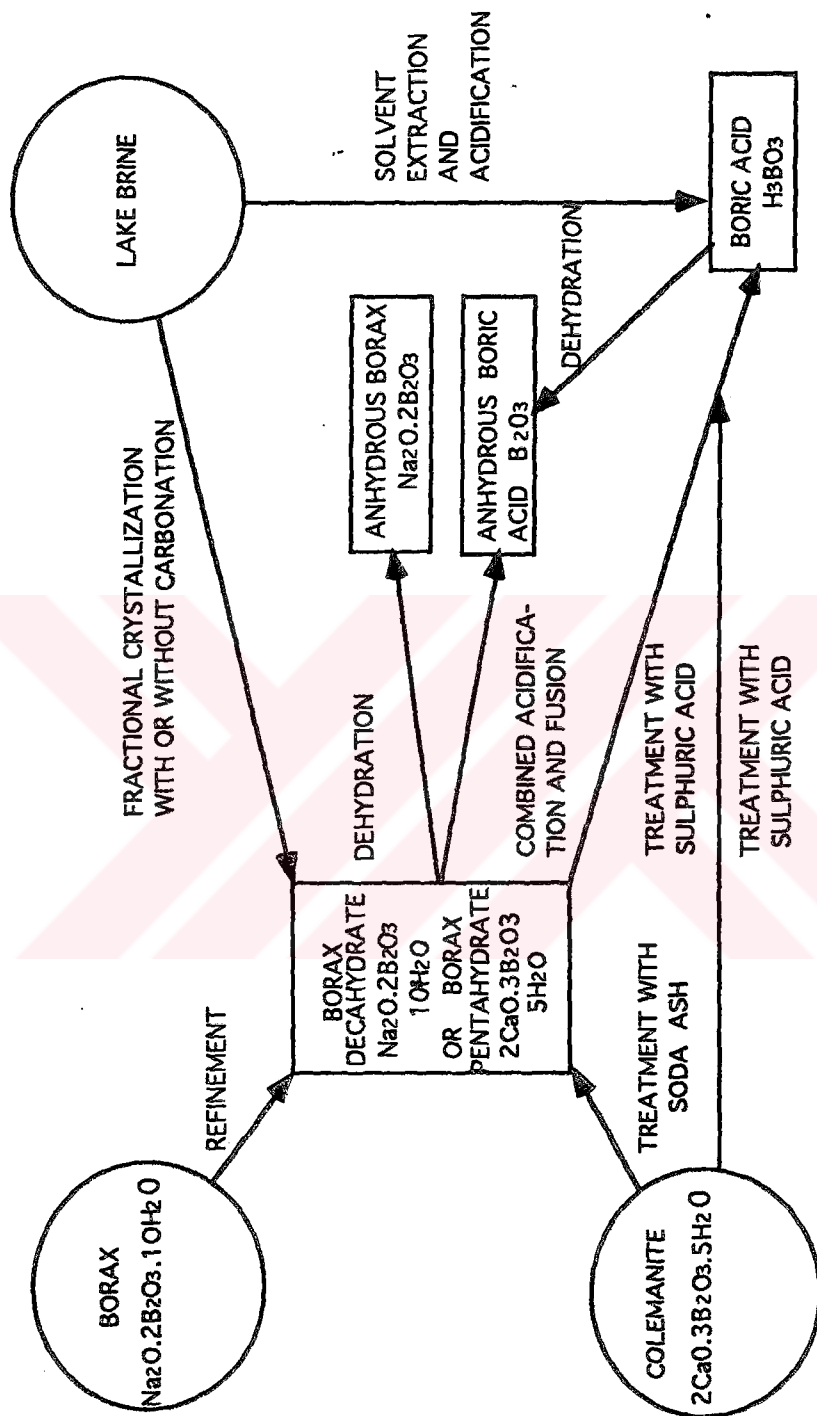


Figure 2: Production of Boron Compounds [1]

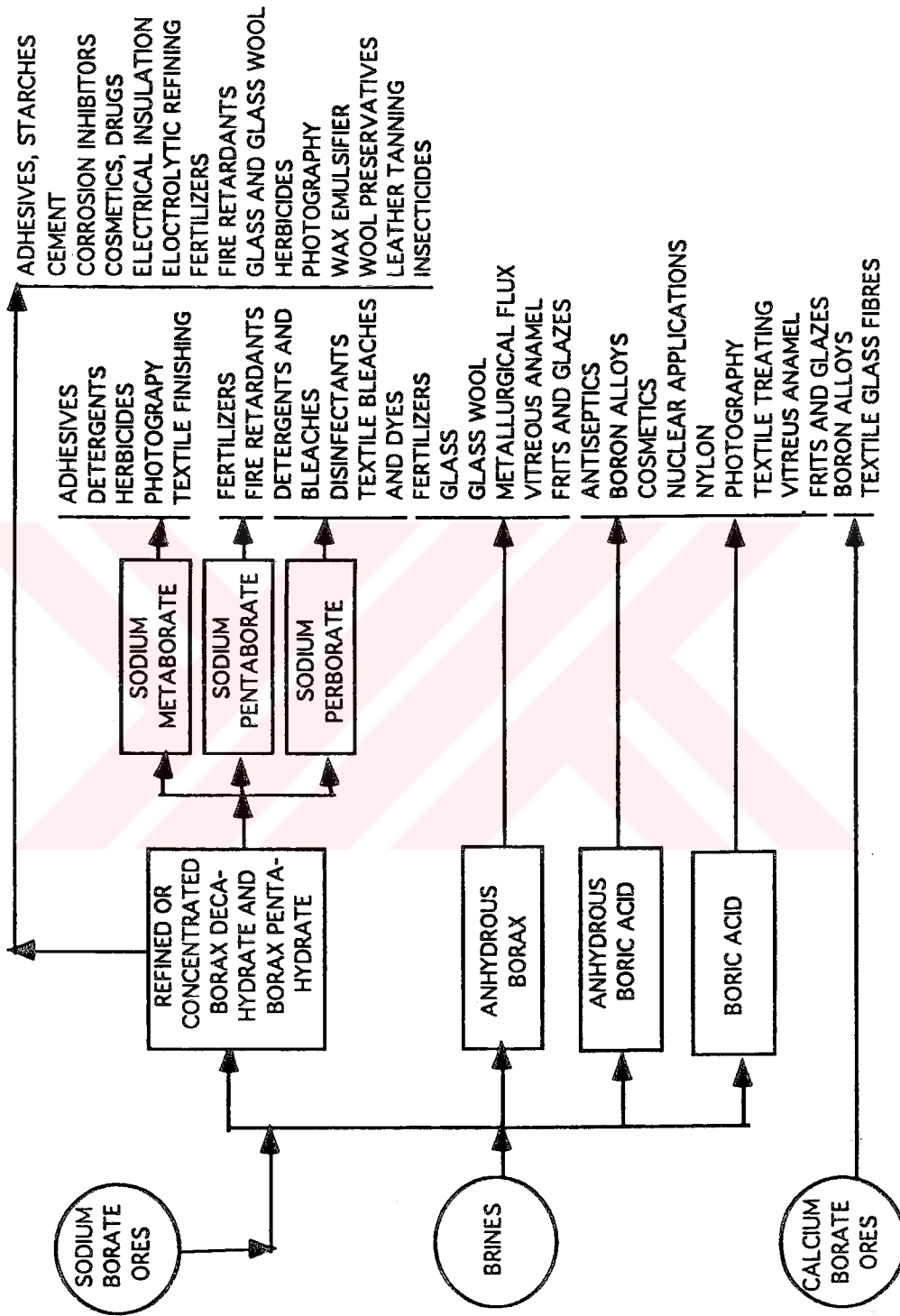


Figure 3: Main Uses of Boron Compounds [18]

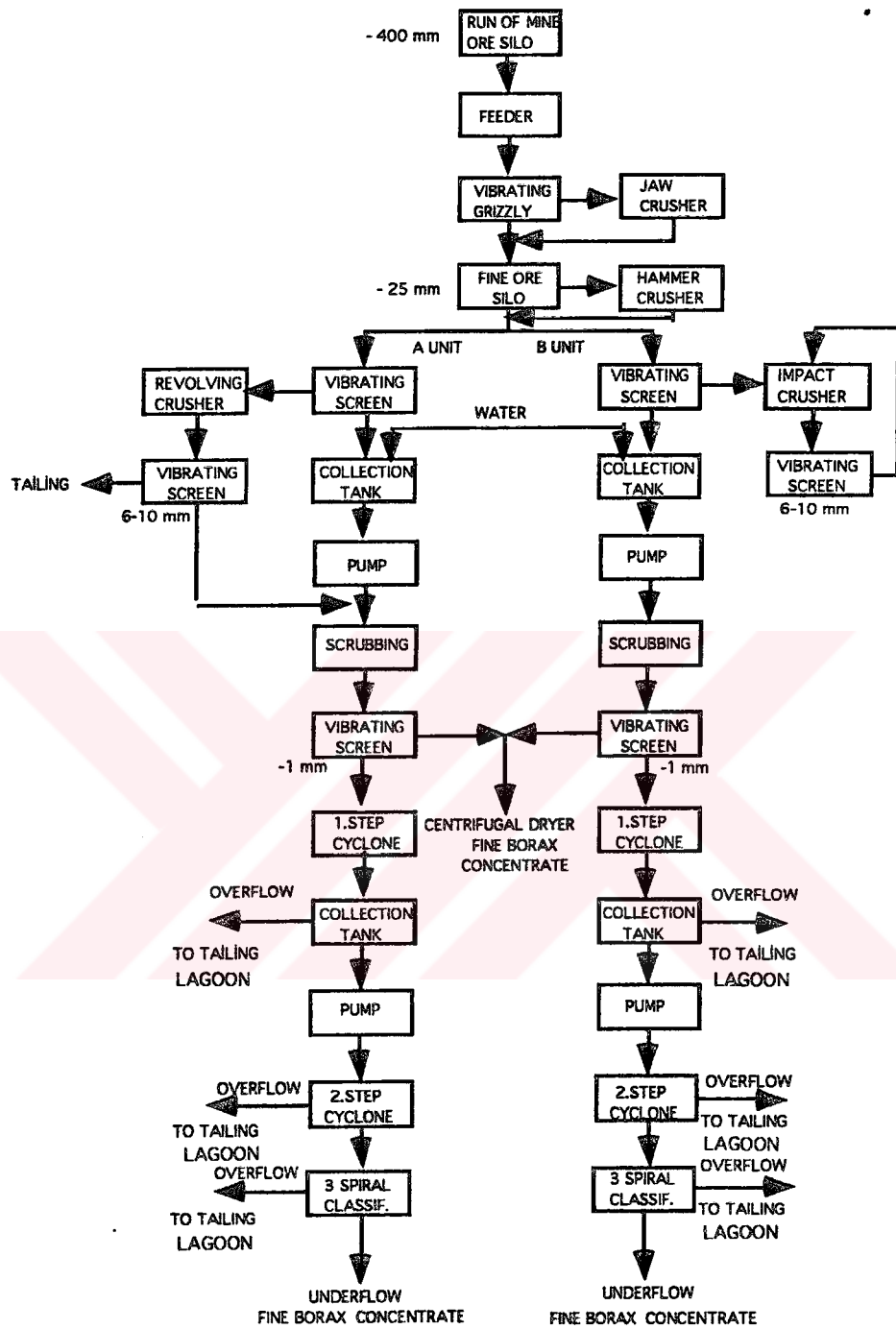


Figure 4: Flowsheet of Kirka Concentrator [3]

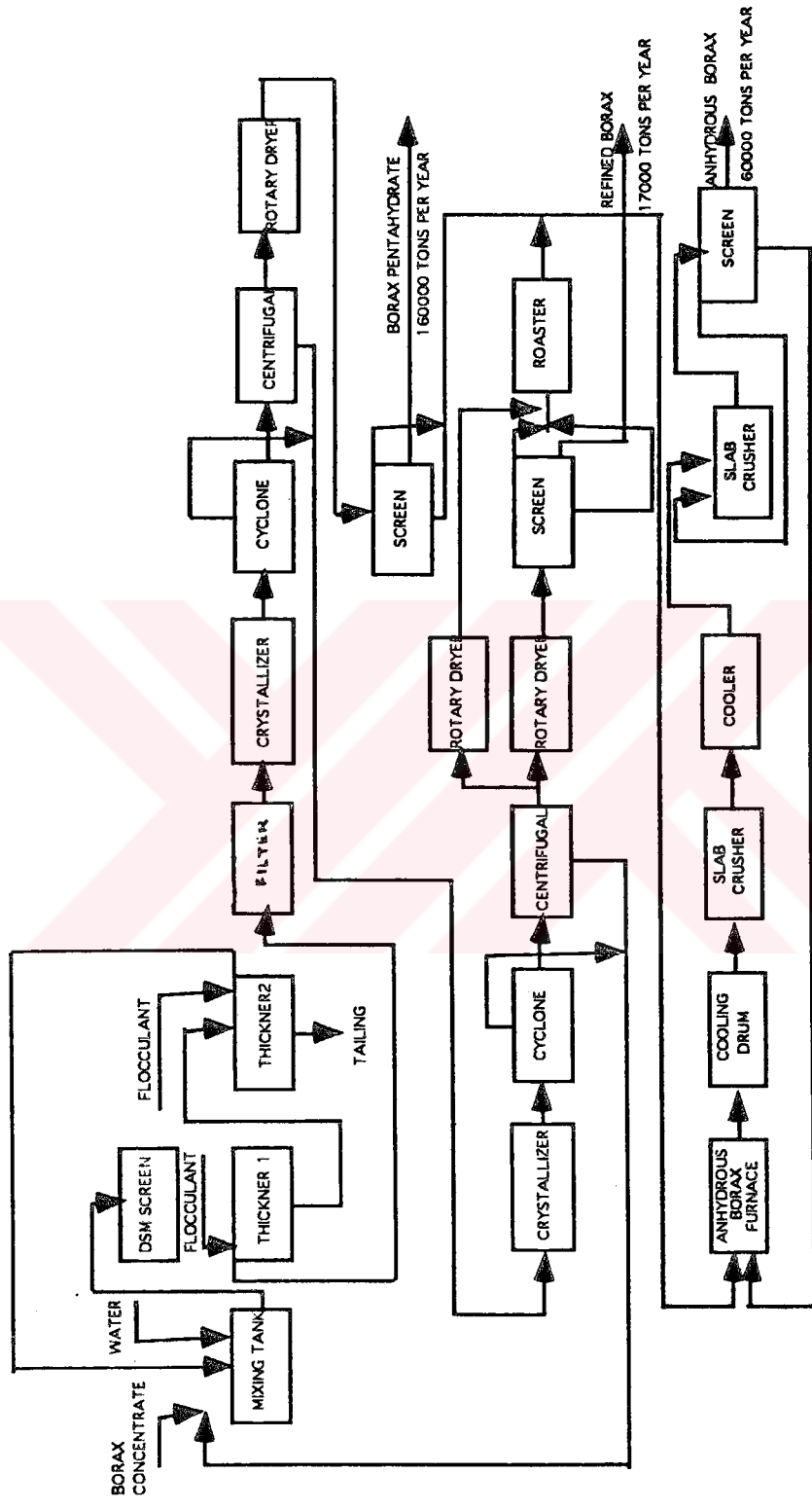


Figure 5: Flowsheet of Kirka Refining Plant [21]

In Kirka Borax Works, about 400,000 tons of clay is removed per year. 250,000 tons of this clay is from the concentrator. In the concentrator a small amount of this clay is mashed in rollers and is removed as a paste. The clay removed by cycloning and mechanical classification is sent to the tailing ponds by canals. The tailings clay removed from the refining plant is about 150,000 tons and removed from the DSM screen and three thickeners. This is also sent to the tailing ponds [22].



CHAPTER 3

MATERIALS AND METHODS

3.1. Materials

The tailings material was taken from the tailings pond of Kırka Borax Works and brick clay was taken from Kılıçoğlu Brick Factory in Eskişehir. These materials were dried in atmosphere and ground to - 28 mesh. Apart from the bricks containing normal tailings, the bricks were also manufactured by using calcined tailings in this study to produce the bricks of different quality and structure. Therefore, half of the tailings material was calcined to remove water that placed in borax.

Table 4 : Chemical Analysis of Tailings, Calcined Tailings, and Brick Clay

COMPOUND (%)	TAILINGS	CALCINED TAILINGS	BRICK CLAY
B ₂ O ₃	8.15	9.63	----
SiO ₂	18.74	22.13	41.43
Al ₂ O ₃	3.24	3.91	4.17
Fe ₂ O ₃	0.47	0.56	7.64
CaO	21.85	25.89	10.77
MgO	16.63	19.64	6.27
K ₂ O	0.33	0.39	----
Na ₂ O	6.83	8.06	----
Loss on ignition	22.83	8.86	27.01

In Kirka Deposit, clay minerals are principally montmorillonite and vermiculite. Illite and chlorite are also found rarely[23]. Chemical analysis of the tailings calcined tailings, and brick clay are given in Table 4.

3.2. Methods

At first, pure brick mud was prepared by mixing 20 percent water with the brick clay. Then, five kinds of brick muds were prepared by mixing 20 percent water with the brick clay and the tailings material. In each mud, the tailings material was used in the quantities of 10 %, 20 %, 30 %, 40 % and 100%. In the same way, brick mud was prepared by mixing 20 percent water with the brick clay and the calcined tailings material. In each mud, the calcined tailings material was used in the quantities of 10 %, 20 %, 30 %, 40 % and 100 %. Mixings were carried out by hand.

The bricks were shaped under a load of 350 kg/cm² as 38.8 mm in diameter and 26.00 mm in height by using a cylindrical mold, shown in Figure 6, and a press machine, shown in Figure 7. Press machine has a loading capacity of 200 tons. The shaped bricks were weighed for plasticity water test and marked for drying shrinkage test, and then dried in atmosphere for a week and in a furnace at 50°C, 60°C, 70°C, 80°C, 90°C, and 100°C for 24 hours. Following the drying process, weighing and marking actions were repeated. Then plasticity water and drying shrinkage tests were carried out on the dried bricks. Afterwards, dried bricks were fired in a metallurgical furnace, shown in Figure 8, at 700°C, 800°C, and 900°C to 4.5 hours. The temperature was raised to some specified degree ranges in the following time periods:

Temperature (°C)	Period (Min)
0-200	75
200-400	120
400-600	120
600-700	60
700-800	60
800-900	60



Figure 6 : Cylindrical Mold



Figure 7 : Press Machine



Figure 8 : Metallurgical Furnace

Finally, firing loss and compressive strength tests were carried out on the fired bricks. The other tests, namely, water absorption, frost resistance, weight per unit volume, harmful magnesia and lime, and firing shrinkage tests were carried out on these bricks with the highest compressive strength.

Each test mentioned above was carried out on five bricks and the averages of the results were reported herein.

3.3. Brick Tests

3.3.1. Compressive Strength Test

The compressive or crushing strength is determined by applying a gradually increasing pressure by a press machine to brick specimens of known cross section until the specimens break or are deformed to a certain amount which is decided upon as the end of the test. The features of the press machine used in this study are as follows:

Trademark	: Tinius Olsen
Hp	: 3
Rpm	: 1500
Volt	: 380
Amps	: 6
Load	: 200 Tons

The compressive strength is calculated as follows[12, 27, 28]:

$$\text{Compressive strength, } C = W/A$$

Where:

C= compressive strength of the specimen, (or kg/cm^2)

W= crushing load, (or kgf)

A= cross section area of the specimen, cm^2

3.3.2. Water Absorption Test

Brick specimens are dried in an oven at $105 \pm 5^\circ\text{C}$ and until two successive weighings at intervals of 4 h show an increment of loss not greater than 0.1 % of the last previously determined weight of the specimens. Following the drying action, the specimens are cooled in a room at a temperature of $24 \pm 8^\circ\text{C}$ and cleaned from the dusts by using a brush. Then the specimens are weighed to the nearest 1g, and the dry weight (W_d) is determined.

Dried specimens are submerged into a water tray, in which each specimen stands in 1/4 of the depth of water. Sufficient water is poured an hour later so that specimens stand in the half of the depth of water, and two hours later so that the specimens stand in 3/4 of the depth of water. 24 hours later from beginning, specimens are sunk completely by adding water. After waiting for 48 hours, specimens are removed, surface water is wiped off with a damp cloth and weighings are repeated. Therefore, the saturated weight of the specimens (W_s) are determined.

The water absorption of each specimen is calculated as follows[25, 26]:

$$\text{Water Absorption, } W_a \% = 100 (W_s - W_d) / W_s$$

Where:

W_a = Water Absorption, %

W_d = Dry weight of the specimen, g

W_s = Saturated weight of the specimen, g

3.3.3. Frost Resistance Test

The brick specimens are placed in a refrigerator after sinking for 48 hours into water as in 3.3.2. Temperature is regulated to decrease to -15°C in 4 hours. Specimens are remained for 2 hours at -15°C , and removed from the refrigerator. Then, they are completely immersed into a water tray, and remained there for an hour for thawing.

This treatment is repeated 25 times, cracks and deformations developed during freezing are examined. If there is any doubt about the results of the examination, compressive strength test is then repeated and the results are compared with previous strength values [24].

3.3.4. Harmful Magnesia and Lime Test

Test specimens are totally immersed in a water tray and placed there for 24 hours. Water is heated to boiling, within 2 h, and then allowed to cool to the room temperature. Cooled specimens are examined for cracks and deformations. If there is any doubt about the results of the experiments, compressive strength test is then repeated and the results are compared with previous strength values[24].

3.3.5. Shrinkage Test

Length of 100 mm \pm 0.1 mm is marked on the long axis of plastic brick specimens. Specimens are dried, and marked length is measured to the nearest 0.1mm. Measurement is repeated after firing on fired bricks. In this study, shrinkages were measured according to change in diameter since bricks were miniature.

Drying shrinkage is calculated as follows[27]:

$$\text{Drying Shrinkage, } S_d = ((L_p - L_d) / L_p) 100$$

Where:

S_d = drying shrinkage, %

L_p = plastic length of the specimen, mm

L_d = dry length of the specimen, mm

Firing shrinkage is calculated as follows[19]:

$$\text{Firing Shrinkage, } S_f = ((L_d - L_f) / L_d) 100$$

Where:

Sf= firing shrinkage, %

Ld= dry length of the specimen, mm

Lf= fired length of the specimen, mm

3.3.6. Firing Loss, Plasticity Water, and Weight Per Unit Volume Test

Test specimens are weighed respectively after shaping, drying, and firing. Therefore, plastic, dry, and fired weights are determined. In addition, the volume of the fired bricks are calculated.

Plasticity water is calculated as follows[27]:

$$\text{Plasticity Water, PW} = ((W_p - W_d) / W_d) 100$$

Where:

PW= plasticity water, %

Wp= plastic weight of the specimen, g

Wd= dry weight of the specimen, g

Firing loss is calculated as follows[28]:

$$\text{Firing Loss, FL} = ((W_d - W_f) / W_d) 100$$

Where:

FL= firing loss, %

Wd= dry weight of the specimen, g

Wf= fired weight of the specimen, g

Weight per unit volume is calculated as follows[24]:

$$\text{Weight per Unit Volume, WV} = (W_f / V) 1000$$

Where:

WV= weight per unit volume, kg/m³

W_f = fired weight of the specimen, kg

V = Volume of the specimen, m^3



CHAPTER 4

RESULTS AND DISCUSSIONS

In order to determine the effect of the tailings clay addition to ordinary brick clay, bricks with 10 %, 20 %, 30 %, 40 %, 100 % tailings were manufactured. These bricks were fired at 700°C, 800°C and 900°C. In addition, bricks with the same amounts of calcined tailings clay were manufactured and fired at the same temperatures.

In order to determine the properties of bricks, a number of brick tests were carried out. These were plasticity water test, drying shrinkage test, compressive strength test, firing loss test, water absorption test, frost resistance test, weight per unit volume test and harmful magnesia and lime test. Plasticity water and drying shrinkage tests were carried out on the dried bricks with 0 %, 10 %, 20 %, 30 % and 40 % tailings clay and calcined tailings clay. Compressive strength and firing loss tests were carried out on all fired brick groups. However, the other tests were carried out on the bricks with the highest compressive strength.

The results of the compressive strength test, shown in Figure 14, are given in Table 5 and Table 6. At 700°C, the compressive strengths were found to be 170.93 kg/cm² for the bricks with 0 % tailings, 173.25 kg/cm² for the bricks with 10 % tailings, 183.88 kg/cm² for the bricks with 20 % tailings, 189.48 kg/cm² for the bricks with 30 % tailings, 164.35 kg/cm² for the bricks with 40 % tailings. At 800°C, compressive strengths were found to be 191.51 kg/cm², 194.05 kg/cm², 192.40 kg/cm², 204.52 kg/cm² and 172.26 kg/cm² for the same brick groups. At 900°C, strengths were found to be 211.70 kg/cm², 212.83 kg/cm², 219.10 kg/cm², 229.81 kg/cm² and 204.72 kg/cm² for the same brick groups. At 700 °C, the



Figure 9 : Dried Bricks Containing Tailing Clay



Figure 10 : Dried Bricks Containing Calcined Tailing Clay



Figure 11 : Fired Bricks Containing Tailing Clay



Figure 12 : Fired Bricks Containing Calcined Tailing Clay



Figure 13 : All Fired Bricks

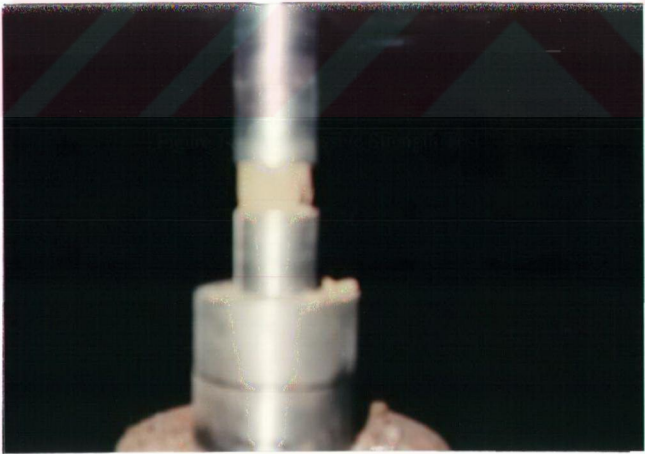
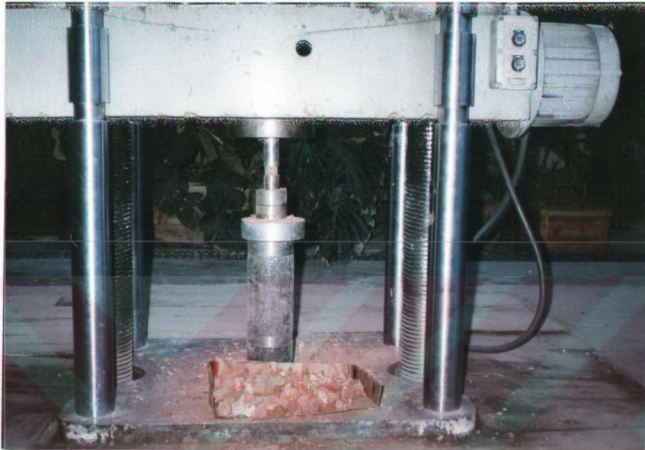


Figure 14 : Compressive Strength Test

Table 5 : Compressive Strength of Bricks Containing Tailing Clay

TAILING PERCENTAGE (%)	700 °C		800 °C		900 °C	
	C (kg/cm ²)	C _{AVER} (kg/cm ²)	C (kg/cm ²)	C _{AVER} (kg/cm ²)	C (kg/cm ²)	C _{AVER} (kg/cm ²)
0	170.76	170.93	190.26	191.51	211.08	211.70
	172.80		191.60		208.37	
	172.43		195.32		208.89	
	168.50		192.90		216.17	
	170.20		187.50		213.99	
10	173.09	173.25	194.27	194.05	213.50	212.83
	174.16		193.62		212.51	
	170.75		196.15		210.63	
	175.21		191.46		217.16	
	173.05		194.78		210.39	
20	183.04	183.88	190.52	192.40	212.10	219.10
	182.00		190.85		225.41	
	181.49		193.29		219.47	
	186.83		194.99		220.34	
	186.04		192.39		218.20	
30	185.62	189.48	206.30	204.52	236.27	229.81
	190.00		200.62		234.21	
	190.09		208.37		225.99	
	192.10		209.36		226.58	
	189.63		197.96		226.01	
40	161.03	164.35	170.23	172.26	209.66	204.72
	160.73		173.98		206.54	
	164.01		172.80		202.84	
	170.00		180.51		205.71	
	165.98		163.81		198.88	
100	CRACKED		CRACKED		MELTED	

Table 6 : Compressive Strength of Bricks Containing Calcined Tailing Clay

TAILING PERCENTAGE (%)	700 °C		800 °C		900 °C	
	C (kg/cm ²)	C _{AVER} (kg/cm ²)	C (kg/cm ²)	C _{AVER} (kg/cm ²)	C (kg/cm ²)	C _{AVER} (kg/cm ²)
0	170.76	170.93	190.26	191.51	211.08	211.70
	172.80		191.60		208.37	
	172.43		195.32		208.89	
	168.50		192.90		216.17	
	170.20		187.50		213.99	
10	75.10	71.79	85.46	89.10	98.00	97.42
	74.50		94.77		92.86	
	69.45		91.28		82.77	
	66.12		90.90		96.07	
	73.78		83.09		107.40	
20	120.30	112.92	112.29	112.19	167.13	163.55
	110.01		113.12		145.55	
	108.47		111.57		151.92	
	108.93		110.80		169.61	
	116.89		113.17		183.54	
30	127.02	130.51	134.90	135.68	172.63	170.70
	125.26		137.01		183.65	
	140.01		138.64		175.02	
	138.75		133.39		160.51	
	132.27		134.46		161.69	
40	146.44	143.06	155.82	151.40	223.79	215.98
	138.12		150.83		213.58	
	140.59		151.47		215.62	
	144.10		145.48		207.93	
	146.05		153.40		218.98	
100	CRACKED		CRACKED		CRACKED	

compressive strengths were found to be 71.79 kg/cm² for the bricks with 10 % calcined tailings, 112.92 kg/cm² for the bricks with 20 % calcined tailings, 130.51 kg/cm² for the bricks with 30 % calcined tailings, and 143.06 kg/cm² for the bricks with 40 % calcined tailings. At 800°C, strengths were found to be 89.10 kg/cm², 112.19 kg/cm², 135.68 kg/cm² and 151.40 kg/cm² for the same brick groups. At 900°C, strengths were found to be 97.42 kg/cm², 163.55 kg/cm², 170.70 kg/cm² and 215.98 kg/cm² for the same brick groups.

Minimum compressive strengths of bricks with a density between 1601 kg/m³ and 1800 kg/m³ should be 80 kg/cm² according to TSE[24]. Therefore, strength values are acceptable.

As a results of the compressive strength tests, it was seen that the strength increased with increasing firing temperature and increased from 0 % tailings clay to 30 % tailings clay. After 30 % the compressive strength started to decrease. In the bricks containing the calcined tailings clay, the compressive strengths are generally lower than that of the bricks containing the tailings clay and the bricks manufactured completely from the brick clay, and increased with increasing firing temperature and the tailings percentage. At 10 % calcined tailings, strength decreased sharply. This may be due to insufficient and dishomogenous mixing, that is , due to insufficient plasticity or may be due to stretchings of plastic bricks during rejection from the mold. Effect of firing temperature and tailings clay addition on the compressive strength of the bricks are illustrated in Figure 15-18.

The increase of the strength with increasing percentage of the tailing clay is due to flux role of borax in the tailing clays. Borax in the tailing clays with silica and other alkalis fused to form glass like material which bound the clay particles together thus rendering the fired bricks strong structure. K₂O, CaO and MgO also act as flux and are found in the tailings clays.

Borax is already used in glass industry due to its fluxing role. Vycor and Pyrex type borosilicate glasses are technically and commercially important.[29] The fluxing power of B₂O₃ can be seen in Table 7 in which maximum used temperature

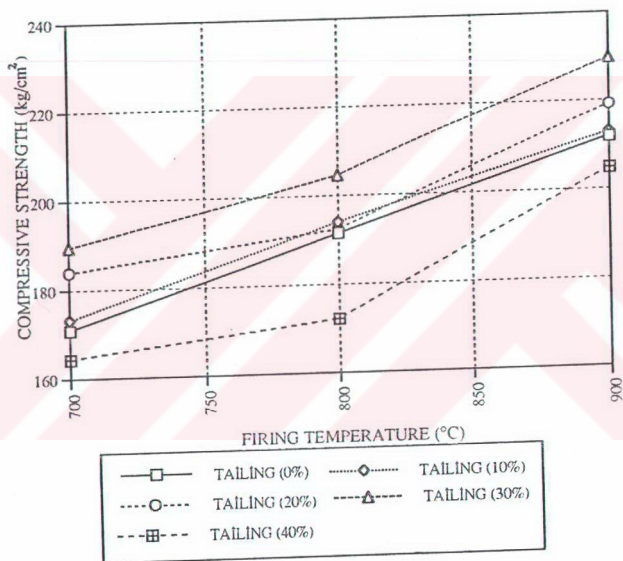


Figure 15: Effect of Firing Temperature on the Compressive Strength of Bricks Containing Tailings Clay.

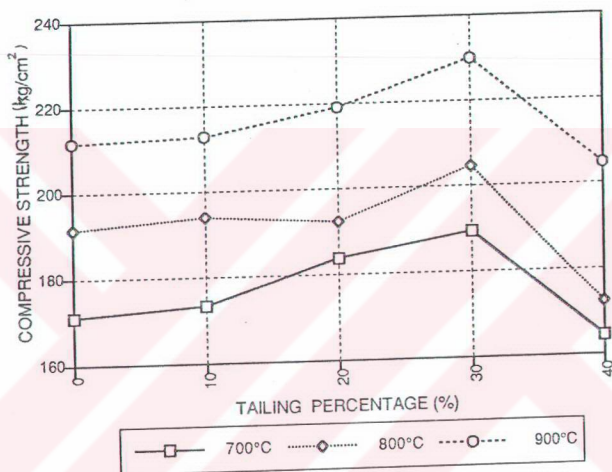


Figure 16: Effect of Tailings Clay Addition on the Compressive Strength of Bricks Containing Tailings Clay.

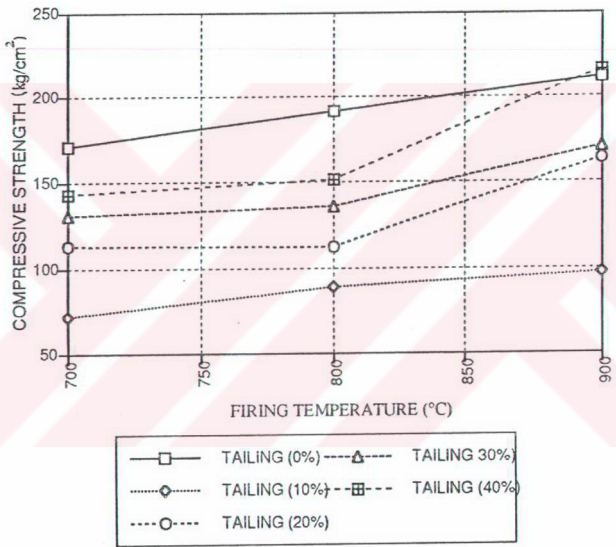


Figure 17: Effect of Firing Temperature on the Compressive Strength of Bricks Containing Calcined Tailings Clay.

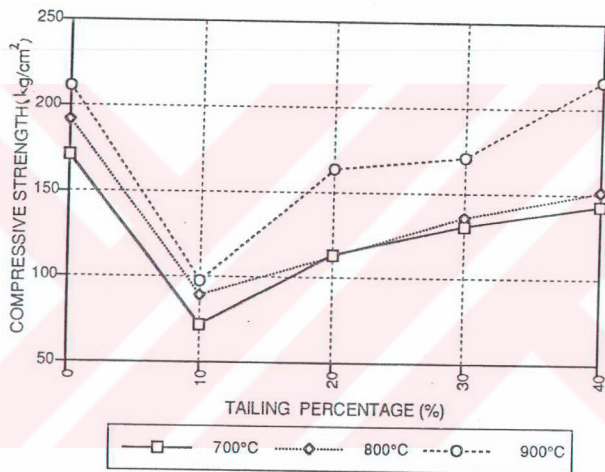


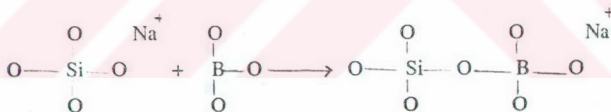
Figure 18: Effect of Tailings Clay Addition on the Compressive Strength of Bricks Containing Calcined Tailings Clay.

in various glasses are compared. Maximum used temperature decreases with increasing B_2O_3 content.

Table 7: Comparison of Various Glasses [30]

Glasses	Major Constituents	Minor Constituents	Max. Used Temp
Borosilicate	B_2O_3, SiO_2	Na_2O, Al_2O_3	600°C
Aluminosilicate	Al_2O_3, MgO, CaO, SiO_2	B_2O_3, BaO	700°C
High Silica	SiO_2	B_2O_3	1150°C

In quartz glass, the silicon atoms are linked to four oxygen atoms at the corners of a tetrahedron. Each of the oxygen atoms is joined to two silicon thus each tetrahedron shares its corners with another forming a continuous network as seen in Figure 19. In sodium silicate glass, alkali metal oxide ion enters into this network and breaks some of the SiO bonds in the network and alkali metal cations occupy the large cavity resulting from the bridge fractured caused by the oxygen as seen in Figure 20. In borosilicate glass, triangularly coordinated B_2O_3 enters into this structure and nonbridging oxygen sites are converted to four coordinated boron sites. This would strengthen the structure. Suggested equation is as follows[31,32]



Another example of fluxing power of B_2O_3 is use of colemanite as slug fluidizer. The strong fluidizing power of B_2O_3 for BOF slugs is illustrated in Figure 21. It can be seen that B_2O_3 provides lower melting point[33].

After the frost resistance test and harmful lime and magnesia test, cracking and deformation were not observed on the bricks. The strength test was repeated for these bricks. Strength values were a bit lower than the initial values and found to be 204.44 kg/cm² for the brick group of 900°C-0 % tailings, 186.35 kg/cm² for the brick group of 700°C-30 % tailings, 201.14 kg/cm² for the brick group of 800°C-30 %

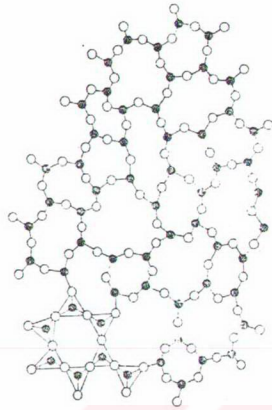


Figure 19: Three Dimensional SiO_4 Tetrahedra in Quartz Glass (Amorphous Silica) [34]

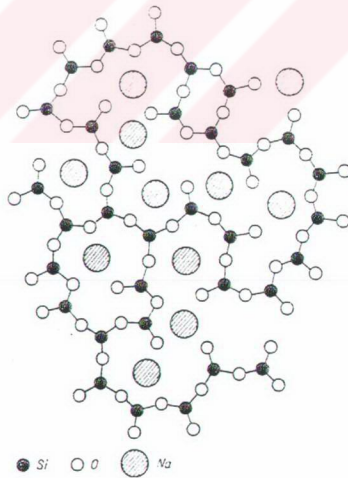


Figure 20: Structure of Sodium Silicate Glass [34]

Point	CaO	B ₂ O ₃	SiO ₂	Temp, °C
1	54.6	1.5	43.9	1,436
2	59.2	16.0	24.8	1,118
3	59.4	16.6	24.0	1,128
4	66.2	14.1	19.7	1,266
5	67.7	13.3	19.0	1,400
6	69.2	12.6	18.2	1,398

Point	CaO	B ₂ O ₃	SiO ₂	Temp, °C
7	69.7	16.2	14.1	1,400
8	70.0	23.2	6.8	1,404
9	69.4	22.8	7.8	1,415
10	55.4	20.4	24.2	1,150
11	45.0	31.7	23.3	1,017
12	38.3	31.5	30.2	977

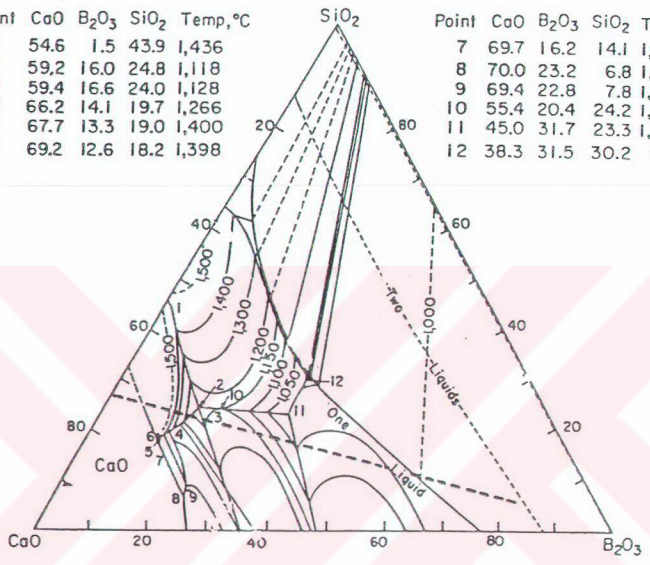


Figure 21: Uses of Colemanite as Slug Fludizer (CaO, SiO₂, B₂O₃ Ternary System) [33]

tailings, 220.08 kg/cm² for the brick group of 900°C-30 % tailings and 208.97 kg/cm² for the brick group of 900°C-40 % calcined tailings, as seen in Table 8.

The differences between the initial compressive strengths and compressive strengths measured after frost resistance test and harmful lime/ magnesia test are not considerable. Compressive strengths measured after frost resistance test and harmful lime/magnesia test should not be lower than 85 % of minimum standard values, according to TSE[24].

Firing shrinkages were found to be 0.41 % for the brick group of 900°C-0 % tailings, 1.90 % for the brick group of 700°C-30 % tailings, 2.16 % for the brick group of 800°C-30 % tailings, 2.24 % for the brick group of 900°C-30 % tailings and 0.35 % for the brick group of 900°C-40 % calcined tailings, as seen in Table 9. Drying shrinkages were found to be 6.35 % for the bricks group with 0 % tailings, 8.81 % for the bricks group with 30 % tailings and 5.90 % for the bricks group with 40 % calcined tailings.

Drying and firing shrinkage of the bricks containing the tailing clay are higher than that of the bricks completely manufactured from the brick clay. The shrinkage in drying is due to removal of water from the brick structure. Removed water percentage in drying is higher in bricks containing the tailing clay than the brick clays due to 10 mole H₂O content of borax. 5 mole of this water is lost during drying from 50°C to 100°C . The shrinkage in firing is due to liquid formation, arising from the combination of fluxing elements with the clay body to form low melting point eutectics. As a result, volume is reduced by decreasing the proportion of void space since formed glassy liquid filled the pores of the structure. On the other hand, drying and firing shrinkage of the bricks containing the calcined tailing clay are lower than that of the bricks completely manufactured from the brick clay. Because the tailing clays were calcined at 200°C for two days. Rapid calcining of borax caused puffing. Puffed borax is composed of small glassy hollow spheres with a void volume as high as 90 % thus causing lower shrinkage. This void volume had already effected the tempering and mixing of the calcined tailing clay with brick clay and these processes had been carried out with difficulty. Because, high percent of

Table 8: Compressive Strength of Bricks After Frost Resistance and Harmful Lime and Magnesia Test

FIRING TEMP / TAILING PERCENTAGE (°C) / (%)	AFTER FROST RESISTANCE TEST		AFTER HARMFUL LIME AND MAGNESIA TEST	
	C (kg/cm ²)	C _{AVER} (kg/cm ²)	C (kg/cm ²)	C _{AVER} (kg/cm ²)
900/0	207.30 204.98 199.89 201.87 208.15	204.44	185.07 180.00 191.87 179.52 187.17	184.72
700/30	186.24 184.73 189.85 183.14 187.83	186.35	174.73 181.05 181.47 178.34 186.72	180.46
800/30	200.43 196.09 201.82 203.94 203.42	201.14	186.69 184.18 182.45 178.91 192.14	184.87
900/30	219.84 219.49 225.35 220.62 215.14	220.08	224.94 214.13 211.51 199.79 194.73	209.02
900/40 (CAL)	207.96 205.73 210.00 217.11 204.06	208.97	194.87 184.68 180.01 200.09 178.96	187.72

Table 9: Drying and Firing Shrinkage of Bricks

FIRING TEMP / TAILING PERCENTAGE (°C) / (%)	DRYING SHRINKAGE		FIRING SHRINKAGE		
	S _d (%)	S _d _{AVER} (%)	S _f (%)	S _f _{AVER} (%)	
900/0	6.38	6.35	0.41	0.41	
	6.25		0.41		
	6.51		0.41		
	6.64		0.43		
	6.25		0.39		
700/30			1.70	1.90	
			1.85		
			2.14		
			2.00		
800/30	8.80	8.81	1.85	2.16	
			2.14		
			1.99		
			2.29		
			2.28		
900/30			2.14	2.24	
			2.13		
			2.13		
			2.43		
			2.27		
900/40 (CAL)	5.85	5.90	2.28	0.35	
			5.98		0.41
			5.98		0.32
			5.59		0.37
			6.11		0.35

mixing water had been adsorbed by this void volume and plasticity had been reduced. This is also the reason of why the strengths of bricks containing calcined tailing clay are generally lower comparing to that of the bricks manufactured completely from the brick clay.

The results of the water absorption test and weight per unit volume test are given in Table 10. Water absorptions were found to be 16.59 % for the brick group of 900°C-0 % tailings, 16.39 % for the brick group of 700°C-30 % tailings, 15.23 % for the brick group of 800°C-30 % tailings, 14.38 % for the brick group of 900°C-30 % tailings and 17.24 % for the brick group of 900°C-40 % calcined tailings. Weights per unit volumes were found to be 1863 kg/m³, 1702 kg/m³, 1707 kg/m³, 1743 kg/m³ and 1638 kg/m³ for the same brick groups.

Although the water absorptions of the bricks containing the tailings clay are lower than that of the bricks manufactured completely from the brick clay, water absorption of the bricks containing the calcined tailings clay are higher. Because, pores in the former bricks are filled by formed glassy material, but in later bricks, void volume due to puffed borax is too high to be filled completely. Weight per unit volume of both bricks containing the tailings clay and the bricks containing the calcined tailings clay are lower than that of the bricks manufactured completely from the brick clay.

Water absorption of building bricks should be <18 % according to TSE[26]. Therefore, water absorption values are acceptable.

Plasticity water and firing loss of the bricks are given in Table 11 and Table 12. Plasticity water contents were found to be 25.38 % for the brick group containing 0 % tailings, 27.60 % for the brick group containing 10 % tailings, 32.65 % for the brick group containing 20 % tailings, 32.41 % for the brick group containing 30 % tailings, 34.69 % for the brick group containing 40 % tailings, and 40.25 % for the brick group containing 100 % tailings. Plasticity water values were found to be 25.38 %, 26.14 %, 28.24 %, 30.55 %, 30.91 % and 32.67 % for the brick groups containing the same percentage calcined tailings. Firing losses were

Table 10: Water Absorption and Weight Per Unit Volume of Bricks

FIRING TEMP / TAILING PERCENTAGE (°C) / (%)	WATER ABSORPTION		WEIGHT PER UNIT VOLUME	
	Wa (%)	Wa _{AVER} (%)	Wv (kg/m ³)	Wv _{AVER} (kg/m ³)
900/0	17.18	16.59	1954	1863
	16.94		1888	
	16.55		1771	
	16.01		1843	
	16.28		1859	
700/30	16.74	16.39	1766	1702
	16.03		1654	
	16.79		1716	
	16.45		1693	
	15.96		1682	
800/30	16.27	15.23	1755	1707
	15.42		1705	
	13.86		1688	
	15.50		1701	
	15.12		1690	
900/30	14.14	14.38	1697	1743
	14.55		1703	
	14.29		1812	
	14.68		1793	
	14.26		1712	
900/40 (CAL)	17.01	17.24	1621	1638
	17.46		1648	
	17.73		1642	
	17.08		1659	
	16.92		1623	

Table 11: Firing Loss and Plasticity Water of Bricks Containing Tailing Clay

TAILING PERCENTAGE (%)	700 °C		800 °C		900 °C		PW (%)	PW _{AVER} (%)
	FL (%)	FL _{AVER} (%)	FL (%)	FL _{AVER} (%)	FL (%)	FL _{AVER} (%)		
0	7.93	7.79	9.40	9.22	9.60	9.54	24.50	25.38
	7.70		9.35		9.66		25.89	
	7.77		9.30		9.61		25.67	
	7.74		9.01		9.55		26.45	
	7.84		9.07		9.31		24.42	
10	9.39	9.42	10.37	10.35	10.66	10.62	28.58	27.60
	9.46		10.44		10.88		27.07	
	9.53		10.38		10.51		26.80	
	9.50		10.27		10.75		28.96	
	9.25		10.33		10.50		26.63	
20	11.61	11.65	12.65	12.56	12.74	12.74	34.04	32.65
	11.62		12.77		12.70		33.68	
	11.64		12.56		12.76		32.30	
	11.89		12.18		12.75		31.26	
	11.49		12.65		12.78		32.00	
30	13.65	13.65	14.34	14.38	15.13	15.15	31.02	32.41
	13.70		14.28		15.06		33.93	
	13.69		14.56		15.20		32.49	
	13.47		14.38		15.11		31.68	
	13.74		14.37		15.27		32.95	
40	16.18	16.22	16.66	16.63	17.56	17.61	35.05	34.69
	16.29		16.57		17.64		34.40	
	16.07		16.61		17.53		32.62	
	16.24		16.69		17.58		35.58	
	16.36		16.65		17.78		35.81	
100	CRACKED	CRACKED	CRACKED	MELTED	MELTED	39.12	40.25	40.75

Table 12: Firing Loss and Plasticity Water of Bricks Containing Calcined Tailing Clay

TAILING PERCENTAGE (%)	700 °C		800 °C		900 °C		PW _{AV} ER (%)
	FL (%)	FL _{AV} ER (%)	FL (%)	FL _{AV} ER (%)	FL (%)	FL _{AV} ER (%)	
0	7.93	9.40	9.60	24.50	9.60	24.50	25.38
	7.70	9.35	9.66	25.89	9.66	25.89	
	7.77	9.30	9.61	25.67	9.61	25.67	
	7.74	9.01	9.55	26.45	9.55	26.45	
	7.84	9.07	9.31	24.42	9.31	24.42	
10	9.32	10.51	10.82	26.22	10.82	26.22	26.14
	9.04	10.52	10.82	25.48	10.82	25.48	
	8.61	10.60	10.89	25.79	10.89	25.79	
	9.38	10.47	10.87	26.06	10.87	26.06	
	9.38	10.53	10.82	27.15	10.82	27.15	
20	12.48	13.23	13.53	28.33	13.53	28.33	28.24
	12.03	13.24	13.61	27.48	13.61	27.48	
	12.33	13.05	13.49	29.02	13.49	29.02	
	12.44	13.19	13.54	28.64	13.54	28.64	
	12.40	13.20	13.52	27.77	13.52	27.77	
30	13.16	13.42	16.23	30.28	16.23	30.28	30.55
	13.19	13.36	16.20	30.49	16.20	30.49	
	12.64	13.19	16.22	29.63	16.22	29.63	
	13.22	13.32	16.20	32.00	16.20	32.00	
	13.17	13.25	16.18	30.39	16.18	30.39	
40	15.27	15.86	18.74	28.96	18.74	28.96	30.91
	15.21	15.93	18.80	30.96	18.80	30.96	
	15.13	16.14	18.75	32.00	18.75	32.00	
	15.25	15.93	18.66	31.33	18.66	31.33	
	15.71	16.10	18.82	31.31	18.82	31.31	
100	CRACKED	CRACKED	CRACKED	34.15	32.43	31.44	32.67

found to be 9.54 % for the brick group of 900°C-0 % tailings, 13.65 % for the brick group of 700°C-30 % tailings, 14.38 % for the brick group of 800°C-30 % tailings, 15.15 % for the brick group of 900°C-30 % tailings and 18.75 % for the brick group of 900°C-40 % calcined tailings. Firing loss and plasticity water of both bricks containing the tailings clay and the bricks containing the calcined tailings clay are lower than that of the bricks manufactured completely from the brick clay due to high percentage of removed water.

The color of the bricks changed according to the firing temperatures and tailings percentages of the bricks, as seen in Table 13 and Table 14. Brick types which have a red color are as follows:

Tailings Clay (%)	Firing Temp.(°C)
0	800°C, 900°C
10	700°C, 800°C, 900°C
20	700°C, 800°C
Calcined Tailings Clay (%)	Firing Temp (°C)
10	700°C
20	700°C

The color of the other bricks are tone of yellow and brown. However, the bricks manufactured completely from the tailing clays have white color. Although the bricks manufactured from the brick clay and fired at 800°C and 900°C showed red color, red color began to be observed at lower temperature (700°C) in the bricks containing the tailings clays. Red color disappeared with increasing tailings percentage. Because Fe_2O_3 content of the tailing clays and calcined tailings clays are 0.47 % and 0.38 % and lower than that of the bricks manufactured completely from the brick clay which is 7.64 %.

The bricks containing 10 % and 20 % tailings clay have stable structure and smooth surfaces, as seen in Table 13 and Table 14. However, the other bricks containing the tailings clay have stable structure but rough surface. All of the bricks containing the calcined tailings clay have stable structure but freckled and porous

Table 13: Color and Appearance of Bricks Containing Tailing Clay

TAILING PERCENTAGE %	700 °C		800 °C		900 °C	
	COLOR	APPEARANCE	COLOR	APPEARANCE	COLOR	APPEARANCE
0	BROWN	STABLE BRICK	PALE RED	STABLE BRICK	DARK RED	STABLE BRICK
		SMOOTH SURFACE		SMOOTH SURFACE		SMOOTH SURFACE
10	RED	STABLE BRICK	RED	STABLE BRICK	PALE RED	STABLE BRICK
		SMOOTH SURFACE		SMOOTH SURFACE		SMOOTH SURFACE
20	PALE RED	STABLE BRICK	PALE RED	STABLE BRICK	YELLOW	STABLE BRICK
		SMOOTH SURFACE		SMOOTH SURFACE		SMOOTH SURFACE
30	BROWN	STABLE BRICK	YELLOW	STABLE BRICK	BROWN	STABLE BRICK
		ROUGH SURFACE		ROUGH SURFACE		ROUGH SURFACE
40	YELLOW	STABLE BRICK	YELLOW	STABLE BRICK	BROWN	STABLE BRICK
		ROUGH SURFACE		ROUGH SURFACE		ROUGH SURFACE
100	WHITE	DEFORMED BRICK	WHITE	DEFORMED BRICK	WHITE	MELTED BRICK
		CRACKED SURFACE		CRACKED SURFACE		---

Table 14: Color and Appearance of Bricks Containing Calcined Tailing Clay

TAILING PERCENTAGE %	700 °C		800 °C		900 °C	
	COLOR	APPEARANCE	COLOR	APPEARANCE	COLOR	APPEARANCE
0	BROWN	STABLE BRICK	PALE RED	STABLE BRICK	DARK RED	STABLE BRICK
		SMOOTH SURFACE		SMOOTH SURFACE		
10	DARK RED	STABLE BRICK	YELLOW	STABLE BRICK	BROWN	STABLE BRICK
		POROUS AND FRECKLED SURFACE		POROUS AND FRECKLED SURFACE		
20	RED	STABLE BRICK	YELLOW	STABLE BRICK	BROWN	STABLE BRICK
		POROUS AND FRECKLED SURFACE		POROUS AND FRECKLED SURFACE		
30	PALE RED	STABLE BRICK	YELLOW	STABLE BRICK	BROWN	STABLE BRICK
		POROUS AND FRECKLED SURFACE		POROUS AND FRECKLED SURFACE		
40	GREY	STABLE BRICK	WHITISH YELLOW	STABLE BRICK	BROWN	STABLE BRICK
		POROUS AND FRECKLED SURFACE		POROUS AND FRECKLED SURFACE		
100	WHITE	DEFORMED BRICK	WHITE	DEFORMED BRICK	WHITE	DEFORMED BRICK
		CRACKED SURFACE		CRACKED SURFACE		

surface. Porosity and roughness of the surfaces are due to effect of water during removing. The bricks made completely from the calcined tailings clay cracked and deformed at all firing temperatures. The bricks manufactured completely from the tailings clay also cracked at 700°C and 800°C due to same reason, and melted at 900°C due to the fluxing effect of borax.



CHAPTER 5

CONCLUSIONS

Tailings clay of Kırka Borax Works, rich in boron compounds, was tested to determine if this material can be used as an additive in construction brick manufacturing. It was found that addition of this material up to 30% improved the brick quality with regard to compressive strength, water absorption and density without compromising on other qualities. It was also found that firing temperatures lower than generally practiced firing temperature of 900°C could yield bricks with acceptable qualities if tailings clay is used as an additive in brick manufacturing.

As a results of this study change of the properties of bricks by using borax tailings are as follows:

1. Water absorption of the bricks decreased by using tailings clay and increased by using calcined tailings clay.
2. Drying and firing shrinkage of the bricks increased by using tailings clay and decreased by using calcined tailings clay.
3. Density of bricks decreased by using tailings clay and by using calcined tailings clay.
4. Frost resistance and harmful lime and magnesia content of both bricks containing tailings clay and calcined tailings clay were acceptable.

5. The bricks could be fired at 700°C and 800°C. However, strengths of these bricks were somewhat lower. Bricks could not be manufactured completely from the tailings clay and calcined tailings clay because of melting and cracking.

6. Redness of bricks disappeared after 20 % tailings. Bricks with tailings clay were stable and surface of these bricks became rough after 20% tailings clay. Bricks with calcined tailings clay were stable , but, surface of these bricks were porous and freckled.



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