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Utilization of Fly Ash Raw Material as Brick Production: A Review

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Abstract: The production of large quantities of solid wastes in worldwide is increasing because of the areas related to domestic, industrial, commercial and construction. Therefore, environmental problems are arisen day by day with increasing population and improving technological development. The usage of these waste products in the construction materials may be help to reduce the magnitude of this problem. Recycling of materials, the most preferred waste disposal option is an appropriate way to offset the environmental impact associated with the construction sector as an alternative material. This overviewed approach for bricks production addictive material will be useful to provide a potential and sustainable solution for waste control. In this article, the usability of fly ash from thermal power plants on brick construction has been investigated. Moreover, the physical and chemical suitability of this waste material has been investigated as additive for brick production. According to this approach, the requirement to develop a standard mix design for solid waste based building materials need to examine the actual behaviour or performance of these building materials in practice and the requirement of limitation to practical application of these building materials.

Keywords*: fly ash, brick, thermal power plants, recycling, solid wastes*

Introduction

Today, environmental problems are increasing all over the world especially in our country. Urbanization, industrialization depending on population growth is the reasons for these environmental problems [1]. The recycling of construction waste material is a solution to both the environmental pollution problems and economic design of buildings. In the brick industry sector, brick as construction material produce the most solid waste. The brick is a large- scale construction material due to the fact that it usually is used for construction exterior and interior walls in buildings [2]. Turkey Electricity Generation is as below: liquid fuels such as natural gas, hydroelectric, coal and lignite, imported coal, wind, motor and fuel oil, geothermal, biogas and solar energy respectively [11]. Looking at the energy sources which are summarized in Table 1, it is seen that about 35% of the energy sources are from thermal power plants. As an alternative solution to this problem the produced waste from thermal power plants should be used as admixture materials in brick production. Between 2010 and 2014, a total of 24.2 million tons of waste were generated, including 9.1 thousand tons of hazardous waste in thermal power plants. The mineral wastes (ash, slag, fly ash, gypsum, etc.*)* constitute 98.5% of the resulting waste. 48.3% of the total waste is disposed on the ash / ash barrels, 21.7% on the landfills, 15% on sale, or sent to license waste disposal and recovery companies and 15% on other ways (sending to mine and stone quarry, throwing in municipal garbage, etc.). It is thought that by 2020, the annual amount of volatile substances in Turkey will exceed 50 million tons [3].

Table 1. Energy Atlas Distribution of electricity generation in 2017 according to sources (Source: http://www.enerjiatlasi.com/elektrik-uretimi/)

Natural Gas	93.653.140	% 33.44
Hydroelectric	65.994.439	% 23.56
Imported Coal	48.338.291	% 17.26
Coal and Lignite	44.030.344	% 15.72
Wind	16.701.508	% 5.96
Geothermal	4.536.987	% 1.62
Biogas	1.616.299	%0.58
Other Thermal Power Plants	2.214.517	%0.79
Imports	2.988.902	%1.07

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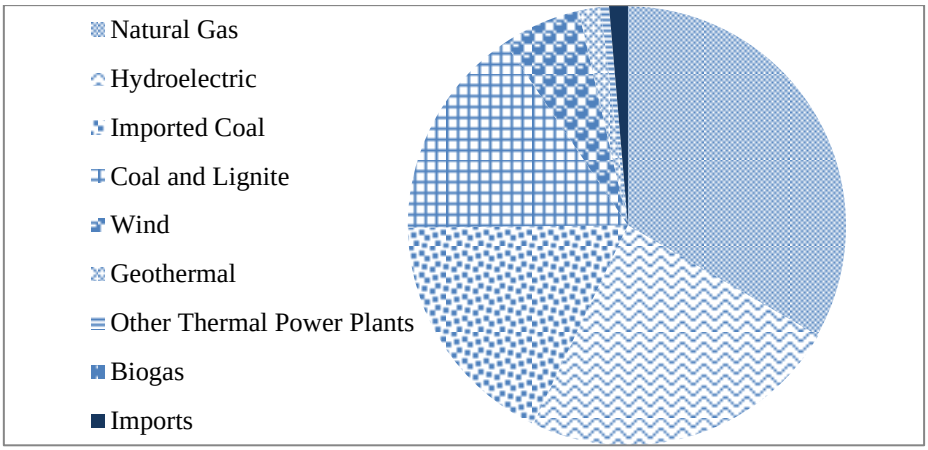

Table 2. Water, Wastewater and Waste Indicators of Thermal Power Plants *(Source: http://www.tuik.gov.tr/PreHaberBultenleri.do?id=18782)*

	2010	**2012**	**2014**
Number of thermal power plants[1]	51	59	66
Amount of water withdrawn (thousand m³ / year)	4285419	6407505	6536015
Amount of cooling water used (thousand m³ / year)	4227027	6334599	6397092
Amount of wastewater discharged (thousand m³ / year)	4167170	6305997	6400042
Amount of cooling water discharged (thousand m³ / year)	4140239	6272802	6307528
Amount of wastewater treated (thousand m³ / year)	17335	15941	13065
Amount of waste (ton / year)	18747759	19252165	24191416
The installed power is 100 megawatts (MW) and above thermal power plants.			

Fly Ashes and Bricks

Thermal Power Plants in Turkey

Parallel to the technological developments in the world and Turkey, the need for energy is increasing. Accordingly, countries try different ways to meet their energy needs, and most of the energy is from primary energy sources such as coal, oil and natural gas. Energy conversion of energy sources is carried out with suitable power plants. Accordingly, some of these plants are shown in the Table 3 [9]. In recent years, natural gas, which is the energy source, has taken its place in Turkey, but this situation has become a cornerstone. The total installed capacity of 39 Coal and Lignite Fired Thermal Power Plants located in Turkey is 17,343,76 MW [10].

Fly Ash and Properties

In the thermal power plants where low-calorie lignite coals are burned, ash particles in the micron size prevent the combustion of the powdered coal during the production of electricity and are driven by the end flue gases and are held by the help of electro filters to prevent atmospheric discharge. These ashes, which are industrial waste and can fly, are called fly ash (UK) [2]. Fly ash is a dark grey colour and very fine grain material. The colour of fly ashes is varying according to the properties of coal burning. Unburned carbon gives black colour to fly ash when the burning process is not sufficient. The colour of fly ash which formed as a result of complete combustion is lighter than the other [4].

The fly ash size depends on the grinding stage of the coal. Another factor that influences the size is that it does not neglect ashes as far away from the pit as possible. The thinner part of the material escaped the more delicate. They are glassy and mostly spherical particles with sizes ranging from 0.5 to 200 microns. Their specific surface ranges from 1800 to 5000 cm / gr and an average of 2800 to 3800 cm^2 / gr [4].

The main constituents in the fly ash are SiO_2, Al_2O_3, Fe_2O_3, and CaO, the others being SO_3, MgO and alkali oxides. In addition, sunburnt carbon, titanium, phosphorus, beryllium, manganese and molybdenum can be found as trace elements. The amounts of SiO_2, Al_2O_3, Fe_2O_3, and CaO, which are basic oxides, vary widely depending on whether the fly ash is silicic or lime-like. Accordingly, in the

fly ash, find out between SiO_2 is 25-60%, Al_2O_3 is 10-30%, Fe_2O_3 is 1-15% and CaO is 1-40% [5, 7, 12, 15, 16, 17, 20].

Table 3. Location and power of thermal power plants in Turkey *(Source: http://www.enerjiatlasi.com/komur/)*

Power Plant Name	Province	Fuel type	Installed Power
Zonguldak Eren (ZETES)	Zonguldak	Imported coal	2790 MW
Afşin Elbistan B Thermal Power	Kahramanmaraş	Lignite	1440 MW
Afşin Elbistan A Thermal Power	Kahramanmaraş	Lignite	1355 MW
İSKEN Sugözü Thermal Power	Adana	Imported coal	1320 MW
İÇTAŞ Bekirli Thermal Power	Çanakkale	Imported coal	1200 MW
İskenderun Atlas Thermal Power	Hatay	Imported coal	1200 MW
Soma B Thermal Power	Manisa	Lignite	990 MW
Kemerköy Thermal Power	Muğla	Lignite	630 MW
Yatağan Thermal Power	Muğla	Lignite	630 MW
Çayırhan Thermal Power	Ankara	Lignite	620 MW
Seyitömer Thermal Power	Kütahya	Lignite	600 MW

Classification of Fly Ash

Classification of Pozzolans illustrated in Figure 1. The subject of this article is the fly ash in the artificial part of the pozzolans. Accordingly, we will briefly discuss on fly ashes and their properties;
In the thermal power plants in the country, coal and lignite coal are used as fuel. Therefore fly ashes divide into 2 groups in the offing coal fly ash and lignite fly ash [3-7-12-15-16-17-20]. According to ASTM C 618 and TS EN 197-1 standards related to chemical structures fly ashes are divided into 4 main classes. In addition, fly ashes are classified into F and C classes according to ASTM C 618 standard. F and C class fly ashes are used because they have pozzolanic and binding effect in brick production [3,7,12,15,16,17,20].

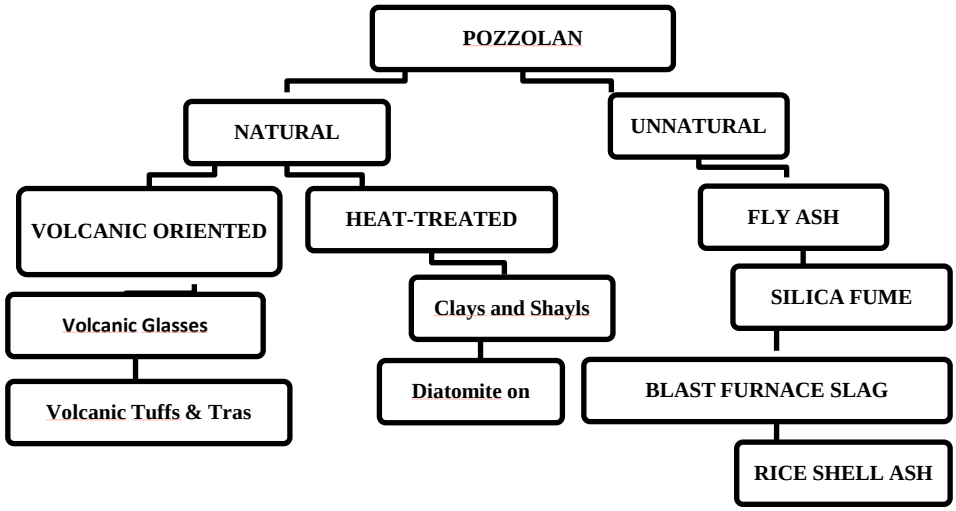

Figure 1. Mineralogical classification of fly ash

It is possible to distinguish 4 basic classes of fly ashes according to chemical structures [3,15,19,20, 21]**:**

1) ***Silicate-alumina based fly ashes:*** *Imported coal is fly ashes and consists of* $SiO_2 + Al_2O_3$.
2) ***Silicate-calcite based fly ashes:*** The main oxides in the formation are SiO_2 and CaCO3.
3) ***Sulfur-Calcite based fly ash:*** The structures compose of SO_3+ $CaCO_3$. This class usually includes lignite fly ash [3-7-12-16-17-20].
4) ***Unclassified fly ashes:*** The combustion systems in the thermal power plants are ashes that do not have a specific chemical structure and are constantly changing [3-7-12-16-17-20].

Generally, in a fly ash are found almost all oxides such as SiO_2, Al_2O_3, Fe_2O_3, CaO, SO_3, MgO, Na_2O, K_2O and TiO_2. However, the of these oxide percentages vary depending on the type of ash. those are chemical properties of fly ash according to TSE and ASTM [3-7-12-16-17-20]:

According to ASTM C 618 standard, fly ash is divided into F and C classes [3-**7**-12-13-15-16-17-20]**:**

a) **F class;** Consists of fly ash produced from bituminous coal and having a total SiO_2 + Al_2O_3 + Fe_2O_3 percentage greater than 70%. These ash are classified as low calcareous because the percentage of CaO is below 10%. Class F fly ash has pozzolanic character.

b) Class C; comprises ashes produced from lignite or semi-bituminous coal and having a total SiO_2 + Al_2O_3 + Fe_2O_3 content of more than 50%. These ash are classified as high calcareous because the percentage of CaO is above 10%. Class C fly ash has a pozzolanic and bonding property.

According to TS EN 197-1, fly ash is divided into two main groups as silicate (V) and calcareous (W) [3-**7**-12-13-15-16-17-20]**:**

a) Class V Fly Ashes; These ashes are composed of the majority reactive SiO_2 and Al_2O_3;consist of the rest of Fe_2O_3 and other components. In these ashes, less than 10% of the reactive lime (CaO) ratio, greater than 25% of the reactive silica amount should be .

b) Class W Fly Ashes; these ashes are composed of the based reactive CaO, reactive SiO_2 and Al_2O_3;consist of the rest of Fe_2O_3 and other components. In these ashes, greater than 10% of the reactive lime (CaO) ratio, less, than 25% of the reactive silica amount should be.

A classification can also be made according to the amount of CaO in fly ash and this classification is made according to the activity of the fly ash and the fly ash activity is understood to be CaO content.
According to fly ash activity;

a) Very low activity ash: CaO <3.5%
b) Low active ash: 3.5% <CaO <7%
c) Active ashes: 7% <CaO <14%
d) Very active ashes: CaO> 14% are in for classified in four different ways

Table 4 shows chemical compositions of some fly ash in Turkey. The fly ash in this table is given in Table 4 together with ASTM C 618 limit values. According to ASTM C 618, Afsin-Elbistan FA is class C and the others FA are class F [7-12-13-14- 15-16-17-20].

Table 4. Chemical compositions of some fly ashes in Turkey

Compound (%)	Afşin-Elbistan	Çatalağzı	Tunçbilek	Çayırhan	ASTM C 618 limits	
					F	C
SiO_2	27.4	56.8	58.59	58.59	-	-
Al_2O_3	12.8	24.1	21.89	21.89	-	-
Fe_2O_3	5.5	6.8	9.31	9.31	-	-
Si+Al+Fe	45.7	87.7	89.79	89.79	>70	>50
CaO	47.0	1.4	4.43	4.43	<10	>10
MgO	2.5	2.4	1.41	1.41	<5	<5
Na_2O	0.3	(N+K) 3.0	0.24	0.24	<1.5	<1.5
K_2O	-	-	1.81	1.81	-	-
SO_3	6.2	2.9	0.41	0.41	<5	<5

The Brick Material

Among the various construction materials, the brick has been used since ancient times in construction and not lost its importance until today. These materials are widely used because they are inexpensive, easy to supply and easy to use. These materials form bricks at first. Brick making in recent years is an important place in the Turkish economy. The brick is the raw material that is clay and mostly used in construction sector. The brick is a building material which is resistant to water, cold and fire. Since the day it was discovered, become an indispensable material which together with has changed design and dimensions. Clay soil, which is the raw material of bricks, is an important material for brick because of its naturalness and cheapness [5].

During the production phase of the brick, the kneaded raw material is rested and the resistance of the mud is ensured. Relaxation is the most important aspect of the raw material preparation stages as it is an important factor affecting the quality of the material [5].

The last stage of brick production is cooked. During cooking, the clay is exposed to chemical reactions. At around 300 ° C organic matter is completely burned, by leaving the molecular water component at 550°C, the mixture decomposes into silica and alumina, At 550-900 ° C, the silica and alumina rejoin to form the meta kaolin silicate (Al_2O_3.2 SiO_2). This new material is now a brick that is hard, does not change its shape, and has a certain strength and colour. Increasing the cooking temperature increases the mechanical strength of the brick, reduces water absorption and increases unit weight. However, the very high cooking temperature causes the brick to be glassed and the property adhesion of the plaster to be reduced. For this reason, the cooking temperature must be between 900 and 980 °C [5].

In the production of sand/lime bricks, the hardness of the material depends on the formation of CaO-SiO_2-2H_2O-(C-S-H) Highly soluble fly ash containing SiO_2 is mixed with lime and steam and used for the production of building material. It is based on the formation of calcium silicate hydrate [23]. In a study conducted by Klimesch & Ray (1998), the phase of CaO-SiO_2-2H_2O-(C-S-H) occurred in the presence of Al_2O_3. Therefore, it has been determined that Al_2O_3 found in fly ash will also contribute to the formation of calcium alumina silicate hydrate in the production of lime-based, steam-blended materials [23].

Fly Ash Usage In Construction Sector

Following the oil crisis, which began in the 1970s in the world, efforts to reduce energy use and to use alternative materials are increasingly continuing. When physical, chemical and mineralogical properties of fly ash are examined, it can be seen that they can be used easily in construction sector. It is also possible to prevent environmental pollution and protect ecological balance [14]**.**

Table 5. Using areas in construction sector of fly ashes

Materials	**Purpose of usage/place**
Cement	As raw material, contribution and substitution material
Aggregate	Fine aggregate, coarse aggregate and light aggregate
Concrete	As contribution and substitution material
Mud brick, brick	As contribution material
Adobe	As binding material
Construction Material	Block, panel, wall, aerated concrete, concrete pipe, glass, paint, ceramic, plastic, mortar
Various constructions / applications	Dam, highway, nuclear power plant, geotechnical applications

Construction sector FA; used in the production of cement, concrete, aggregate, mud brick, brick, aerated concrete and insulation material, dam, road construction and geotechnical applications [14]. Some of the areas where fly ash is used in the construction sector are shown in Table 5. [17]. FA; Cement, concrete, adobe, agriculture, geotechnical studies, building material production, road constructions are used in many areas [14].

Usage FA in Cement

The cement industry is the most important of the FA's widely used areas. Since 1980s, the share of Portland cement production in cement containing an additive in Turkey is over 90% [14]. In the cement of the FA; 1) raw materials, 2) the additive, 3) substitution material appear to be used as [14-18-19]. Raw materials (CaO, SiO_2, Al_2O_3, Fe_2O_3) used in cement making are also found in the composition of fly ash. This is why it can be used in the construction of cement. FA, when used as a cement additive, energy saving is provided. In addition, cement is manufactured at a lower cost. UK cements in Turkey and in the World have a very common area [14].

Usage FA in Adobe Production

A mud brick is known as a traditional building material with low strength and incurable to water [20]. There have also been some researches that used UK in the production of adobe. The results of these studies show that the UK is positively influencing adobe properties and therefore can be used as binding material in mudbrick production [14].

Usage FA in Concrete

Work on the use of UK in the construction industry in the world is usually on concrete. Due to its pozzolanic properties, fly ashes can be used in many areas. Fly ash in concrete mix; Improves workability and ultimate strength, reduces hydration heat, increases strength and reduces permeability despite alkali aggregate reactions and sulphate effect [16,20]. In a study using Class C FA, better quality and lower cost concrete was produced. It has been experimentally determined that when the FA is used in the concrete mixture, the corrosion of the reinforcement in the concrete is reduced. The UK has also been used to reduce the hydration temperature of concrete in the construction of many dams in Turkey and in the World [14].

Usage of fly ash as aggregate

By using lightweight aggregates produced from fly ashes, more economical and environmentally friendly concrete can be produced by lightweight concrete design and production. Lightweight fly ash aggregates exhibit different behaviours due to the different components of fly ash [12-16-20].

It is possible to use F class fly ash instead of slim aggregate in concrete production. The workability, compressive strength, modulus of elasticity modulus and rotre value of fly ash concretes according to control concrete has been progressed positively. It has been found that when fly ash is used in concrete as fine aggregate up to 40%, the wear resistance of concretes is also increased compared to the control concretes [12-16-20].

Usage FA in Brick

Fly ashes are used in brick production because they are very fine grained, give high strength when they are hardened and contain oxides of clay [20-16].

The use of fly ash in the brick industry is limited as it is used in concrete and cement. In Cultrone and Sebastian's work (2009), it has been found that fly ash is used in brick production and that the reference brick specimens are very similar to the produced fly ash-added specimens [7]. In the bricks made with fly ash from the Seyitömer thermal power plant, while fly ash addition to according to reference bricks showed little increase in unit volume weight, did not cause a significant change in drying, and total shrinkage [12-21-22].

It has been determined that brick samples produced using fly ash has lower unit weight and thermal conductivity values than clay produced bricks. It has been found that the heat transfer coefficient values of the test samples are close to values the gas class [12-21-22].

Discussion and Conclusion

Fly ash has a significant environmental impact in solid wastes and needs to be disposed of. Fly ashes have been used in building materials such as concrete, cement etc. in the past and their use in making bricks is insufficient. For the use of fly ash in brick making;

- To prevent environmental pollution and to participate in the economy by evaluating the waste,
- Easy drying,
- Energy saving during cooking like there are advantages.

The use of heavy metals or similar substances with solubility in fly ash in concrete or cement may cause both water and concrete to dissolve as well as demineralized water to reduce the quality of the structure.

However, this risk is inherent because bricks are used as internal building materials. It is also not easy to find brick materials.

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