REVIEW OF RESEARCH ON RECYCLING OF WASTE MATERIALS TO PRODUCE BRICKS THROUGH FIRING

Danuta Barnat – Hunek, Anna Kowalczyk, Katarzyna Stankiewicz

Pope John Paul II State School of Higher Education,
Faculty of Economic and Technical, Department of Technical Sciences
SidorskaSt. 95/97, 21-500 Biała Podlaska, Poland
e-mail: d.barnat-hunek@pollub.pl

Summary:
This paper presents a review of global research on the use of waste materials for production of ceramic building bricks through firing. Main objectives of the directive of the European Parliament and of the Council on waste materials and recycling thereof have been presented herein. Brick production technologies, that have been developed, contribute to improving the natural environment due to the use of waste materials in these technologies. The concept of production of ceramic materials based on waste materials aims at raising awareness with respect to energy saving and environmental protection.

Keywords: waste management, recycling, ceramic brick

Introduction

Poland has faced the necessity to implement solutions oriented towards energy saving and environmental protection due to the EU directives which are becoming more and more stringent. Directive of the European Parliament and of the Council 2008/98/EC of 19 November 2008 on waste materials establishes the legal frameworks concerning waste management in the EU. It defines the key concepts such as wastes, recycling and utilization and it establishes the essential requirements within waste management. It specifies the main principles of waste management in a way that does not have a negative impact on the environment or human health. Main strategy of the Directive is to focus on prevention of generating waste materials and their recycling. There is a great need for recycling and utilization of wastes, finding a recycling method feasible to be generally used. According to the Directive, one should be encouraged to give waste materials for recycling and to use the recycled materials in order to protect natural resources. Every three years the Member States inform the Commission on the implementation of the Directive.

These reports include the assessment of feasibility to implement, at a Community level, programs and measures related to recycling and activities directed towards the recovery of materials and energy, which can contribute to a more efficient use of them, for example in the construction sector for production of building materials which are environmentally friendly (the Directive).

According to the environmental policy of Poland, the objectives of the National Programme for Municipal Wastewater Treatment and the National Waste Management Plan, the amount of waste in Poland is regularly increasing. The priority is to create and use innovative and energy-efficient solutions in construction engineering using building materials made from waste materials. Due to the legislation and standardization requirements of the European Union concerning environmental protection, the management of waste has become a major economic, environmental and technical concern. This increases the need to look for new methods of their utilization, in addition to the existing solutions. There have been a lot of works carried out on waste management projects in all over the worlds in recent years. The increase in the degree of development of civilization and technology has increased the quantities, properties, and harmfulness of the waste generated. This is particularly important due to the presence of, for example heavy metals in wastewater sludge, which is a result of the discharge of municipal and industrial wastewater jointly. Industrial ecology is important from an academic perspective. One of the methods for using waste materials may be to actually use them in production of building bricks after prior having met the conditions set out in PN-EN. Building depots of building materials which are commonly used in building engineering, such as concrete are subjected to modifications, and also the proportions of raw materials for production of lightweight aggregate or ceramic bricks are changed.

Replacing basic components with waste materials causes changes in the structure and physical and mechanical characteristics of the material. Alternative materials allow to lower the production costs and energy consumption, as well as to dispose of waste, however they do not substantially alter the performance of the final product.

Modern technologies allow for the safe management of waste without having a negative impact on natural environment, and the field that the building engineering represents, offers unlimited possibilities of their utilization.

The paper presents a review of the literature on the use of different waste materials to produce traditional building bricks through their firing.

Production of bricks from waste materials – literature research

Along with the occurrence and development of the concept of sustainable development, there has been an increase of public awareness with respect to processing and recycling of waste. This trend can be observed in building engineering, among others in production of bricks by using recycled waste. Worldwide research is being conducted on the properties of waste materials and the feasibility of reusing them. For environmental protection and sustainable development, many researchers have studied the utilization of waste materials

to produce bricks. A wide variety of waste materials have been studied, including fly ash, mine tailings, slags, construction and demolition (C&D) waste, wood sawdust, cotton waste, limestone powder, paper production residue, petroleum effluent treatment plant sludge, kraft pulp production residue, cigarette butts, waste tea, rice husk ash, crumb rubber, and cement kiln dust (Zhang, 2013).

The research on methods for producing bricks from recycled materials can be divided into categories such as firing, cementing and geopolymerization.

First method uses mine tailings or fly ash to substitute a portion or entire amount of clay. Then, the formed products are kiln fired at a high temperature in a traditional way.

Cementing method does not require kiln firing but it is based on cementing from waste or other added cementing materials.

Geopolymerization is a method that relies on chemical reaction of amorphous silica, alumina, solids rich with alkaline solutions at ambient temperature or slightly increased temperature (Zhang, 2013).

Beneficial chemical and mineral composition of waste materials seems to be an interesting alternative both from the industrial and environmental point of view, to produce ceramic materials such as: clay brick.

A wide range of waste materials is used in production of bricks, which include, inter alia, fly ashes which increase tightness. Various industrial wastes such as urban sewage sludge, bagasse, and sludge from the brewing industry, olive mill wastewater, and coffee ground residue were blended with clay to produce bricks.

Municipal solid waste and slag decrease the rate of water absorption, reduce shrinkage formed during firing. Waste foundry sand, due to high level of silica contained therein improves the hygroscopic properties of the samples (Lin, 2006).

Waste glass has got a positive effect on mechanical properties of the material as it reduces its porosity, limits the absorption of water and decreases sintering temperature thus reducing energy consumption (Dębska, 2010).

Paper processing residues, as well as cigarette butts can be used in the production of light and porous bricks due to the low mass and reduced thermal conductivity (Aeslina and others, 2010).

Rice husks reduce linear shrinkage due to the lower water content (Rahman, 1987)

Petroleum effluent treatment plant sludge reduces water content needed for the production of bricks (Faria and others, 2012)

Cleaned river sediments improve the compressive strength of specimens, decrease their porosity and water absorption and reduce the possibility of shrinkage occurrence (Samara and others, 2009).

Marble dust had a positive impact on physical, chemical and mechanical properties of the produced industrial brick (Bilgin and others, 2012)

Using “Waelz” slag supports plastic properties of the tested material, decreases water absorption, limits porosity and reduces the emission of CO2 and NOx during the process of firing (Quijorna and others, 2012).

Sugar cane waste consists mainly of crystalline silica particles, which can be used as filler in brick (Faria and others, 2012).

Next part presents the method of making bricks from waste materials through firing and the tests that the produced samples were subjected to as well as results of analyzes observed.

Tab. 1. Research on recycling of waste materials to produce bricks through firing

Waste material		Tests conducted	Fiving condition	Scientist
1.	Saw dust (0-10%), spent earth from oil filtration(0-30%), compost (0-30%), marble(0-20%)	Compressive strength, water absorption, bulk density, apparent porosity	Specimens of 30x10x60 mm fired in a laboratory furnace at 3°C/min and at 950-1050°C for 4 hours	D. Eliche-Quesada, FA. Corpas- Iglesias , L. Pérez-Villarejo, FJ. Iglesias-Godino
2.	Municipal wastewater sludge (15%), sugarcane bagasse (2,5%), oil production residues (6,5%), coffee ground residues (3%)	Linear shrinkage, bulk density, water absorption, compressive strength, thermal conductivity	Specimens oven dried at 110°C for 24 hours, then weighted and cooled for 24 hours in water. Dried with cloth and weighted again. Specimens weighted every 24 hours.	D. Eliche-Quesada, C. Martínez-García, M.L. Martínez-Cartas, M.T. Cotes-Palomino, L. Pérez-Villarejo, N. Cruz-Pérez, F.A. Corpas-Iglesias
3.	Hematite tailings (77-100%), fly ash (0-8%)	Compressive strength, water absorption, bulk density	Cylinder specimens of 50x50mm dried at 105°C for 6-8 hours and then fired in an electric furnace at 850-1050°C for 2 hours.	Y. Chen, Y. Zhang, T. Chen, Y. Zhao, S. Bao
4.	Fly ash (0, 50, 60, 70, and 80%)	Compressive strength, water absorption, bulk density, apparent porosity, cracking due to lime, frost and frost-melting	Specimens of 60x60x25mm dried at ambient conditions for 2 days, at 60°C for 4 hours, at 100°C for 6 h, and fired in an electric furnace at 100°C/h below 500°C, 50°C/h from 500°C do1000, 1050 or 1100°C, and at the highest temperature for 8h.	X. Lingling, G. Wei, W. Tao, Y. Nanru
5.	Class C fly ash (0%, 20%, 40%, and 60%)	Compressive strength, water absorption	Specimen of 95x45x45mm dried at ambient conditions for 2 days, and then fired in a laboratory at 850 and 1000°C respectively for 24 h,	S.Kute, SV. Deodhar

6.	Class F fly ash (0-60%)	Compressive strength, water absorption, leaching	Specimen of various sizes fired like bricks of clay	MI. Chou, CJ. Laird, KK Ho, SF. Chou, V. Patel, MD. Pickering, JW. Strucki
7.	Fly Ash (100%)	Compressive strength, water absorption, modulus of rupture, density, bond strength, durability	Dried for 3 days, and then fired at 1000-1300°C	O. Kayali
8.	Granite sawing wastes (0-60%)	Compressive strength, water absorption, modulus of rupture	Various sizes of filings fired at different temperatures between 750a1200°C	RR. Menezes, HS. Ferreira , GA. Neves , HdL. Lira, HC. Ferreira
9.	Municipal solid waste incinerator, slag (0-40%)	Compressive strength, water absorption, density, firing shrinkage, weight loss on ignition, TCLP	Specimens of 50x25x50mm air-dried at room temperature for 24 hours, then oven--dried at 80°C for 24 h, and finally fired at 800, 900, or 1000°C for 6 hours	KL. Lin
10.	Gold mill trailings (0-75%)	Compressive strength, water absorption, linear shrinkage	Specimens of 100x100x76mm dried at room temperature for 2 days, in the sun for 3 days, and then fired in an electric furnace at 750, 850 or 950°C for 9 hours	S. Roy, GR. Adhikari, RN. Gupta
11.	Kaolin fine quarry residue (50%), granulated blast-furnace slag (10-40%), granite-basalt fine quarry residue (10-40%)	Compressive strength, water absorption, bulk density	Specimens of 50x50x50mm dried in an electric dryer at 80°C for 24 h, and then fired at different temperatures 1100,1125, 1150 and 1175 oC at 5 °C / min and 4h soaking time in a muffle furnace under oxidizing conditions	MS. El-Mahllawy

12.	Paper production residues (0%, 10%, 20% and 30%)	Compressive strength, water absorption, bulk density, apparent porosity, thermal conductivity	Specimens of 85x85x10mm held overnight at room temperature followed by drying at 45°C for 1 hour in an oven, and then fired in an electric furnace at 2,5°C/min until 600 °C and then at 10°C/min until 1100 °C, for 1 hour	M. Sutcu, S.Akkurt
13.	Cigarette butts (0%, 2,5%, 5% and 10%)	Compressive strength, water absorption, density, thermal conductivity, leaching	Specimens of 300x100x50mm dried at 105 oC for 24 h, and then fired in a furnace at 1050°C	AK. Aeslina, M. Abbas, R. Felicity, B. John
14.	Rice husk ash (0%, 5%, 10%, 15% and 20%)	Compressive strength, water absorption, density,	Specimens dried in the sun at 30°C for 8 days, at 105°C up to 24 h in an oven and then fired in a furnace continuously at 250, 500, 750°C for 2h, and finally at 1000 °C for 2, 4 or 6 h	MA. Rahman
15.	Petroleum effluent treatment plant Sludge (41%)	Compressive strength, water absorption, leaching	Specimens of 280x130x170mm dried at room temperature, and then fired in a coal-fired brick kiln at 1000-1100°C	P. Sengupta , N. Saikia, PC. Borthakur
16.	Kraft pulp production residue (2,5%)	Compressive strength, water absorption, density	Dried at 21°C for 72 hours at 105°C in an oven, and subsequently fired at 2°C/min until 600°C, and then at 5°C/min until 900°C for 30 min	I.Demir , MS. Baspinar, M. Orhan

17.	Waste tea (5%)	Compressive strength, water absorption, density	Specimens of 100x70x40mm dried at 21°C for 72 hours and then at 105°C in an oven, and subsequently fired at 2 oC/min until 600°C , and then at 5°C/ min until 900°C for 2 hours	I.Demir
18.	River sediment (15%)	Compressive strength, water absorption, porosity, firing shrinkage, leaching, permeability, freeze-thaw	Specimens of 60x220x22mm dried through a tunnel drier at 80°C , and then fired through a tunnel kiln with a maximum temperature of 1000°C	M. Samara, Z. Lafhaj, C. Chapiseau
19.	PC and TV waste glass (<2%)	Bending strength, water absorption, open porosity, bulk density, firing shrinkage, leaching	Specimens of 100x20x10mm dried at ambient temperature for 48 hours and then in an electric oven at 100°C overnight, and finally fired in an electric chamber kiln at 100°C / h until 900, 950 or 1000°C for 4 hours	M. Dondi , G. Guarini, M. Raimondo, C. Zanelli
20.	Municipal solid waste incineration fly ash (20%)	Compressive strength, water absorption, porosity, shrinkage, leaching,	Dried at around 60°C and then fired at 950°C	Z. Haiying, Z. Youcai, Q. Jingyu
21.	Foundry by-products (0-50%)	Flexural strength, water absorption, density, apparent porosity	Specimens of 150x30x15mm fired in a muffle furnace at 2°C/min up to 850, 950 or 1050°C for 3,5 h	R. Alonso-Santurde, A. Coz, JR. Viguri, A. Andrés
22.	Waste marble powder (20-100%)	Flexural strength, water absorption, bulk density, apparent porosity	Specimens of 41x8x8mm fired in an electric furnace at 5°C/min up to at 900, 1000 or 1100 for 3 h	N. Bilgin, HA. Yeprem, S. Arslan, A. Bilgin, E. Günay, M. Marsoglu

23.	Slag and waste foundry sand (20-40%)	Flexural strength, water absorption, density, open porosity, leaching	Objects of 100x80x20mm dried at 96-104°C in an industry tunnel kiln to a maximum 850°C	N. Quijorna, A. Coz, A. Andres, C. Cheeseman
24.	River sediment (100% or 50%)	Compressive strength, water absorption, firing shrinkage, freeze-thaw	Dried in an oven at temperature gradually increasing from 25 to 110°C until no change in mass, and then firing in an electric laboratory furnace at different temperatures from 900 to 1000°C with variations in heating rate holding duration at the maximum temperature	A. Mezencevova, NN. Yeboah, SE Burns, LF. Kahn, KE. Kurtis
25.	Sugarcane bagasse ash waste (up to 20%)	Linear shrinkage, water absorption, apparent density, tensile strength	Dried at 110°C for 24h then fired in an electric kiln at 1100°C (24h cold to cold)	KCP. Faria, RF. Gurgel, JNF. Holanda

Analyzing the above table one can see that many researchers have used different types of waste materials in their studies concerning the production of bricks.

Numerous tests have been conducted on the manufactured bricks in order to evaluate the diversity of their properties. The firing temperature ranged from 950 to 1300°C. The physical, chemical and mechanical properties of the bricks were evaluated.

The compressive strength and water absorption are two basic parameters that define the usefulness of the manufactured product to be used in construction.

The research shows that adding municipal wastewater sludge, brewing industry sludge, bagasse creates pores decreasing the compressive strength, but increasing the thermal insulation properties of the bricks.

Maintaining the compressive strength while improving the thermal properties can be achieved by means of using olive mill wastewater and coffee ground residue.

Lighter products with the same physical properties can be achieved by adding such materials waste as sawdust or compost. Adding this type of material improves the porosity and the compressive strength, thus reducing the absorption of water.

Fig. 1. Ceramic brick produced with sawage sludge (Herek and others, 2012).

Fig. 2. The industrial production of the ceramic materials made of clay, sewage sludge and forest waste (Devant and others, 2011).

The results show an improvement in the compressive strength and an decrease of water absorption of bricks which are made by means of using fly ash, due to its fine structure.

Using marble dust has a positive impact on the physical, chemical and mechanical properties of the produced industrial brick due to an increase in size while increasing the porosity and decreasing the mass.

Summary

This paper presents a review of research on utilization of waste materials to produce bricks. In the worldwide literature one may find many examples which prove the feasibility to use waste materials in the production of building ceramics i.e. wastewater sludge from galvanization wastewater, municipal wastewater sludge, polymers waste, slag, industrial ashes, vegetable waste for example sawdust, sugar cane, linen hemp, river sediments and many others.

Examples of the use of waste produced as a by product in mining, municipal, agricultural and other industry presented in this paper confirm the feasibility of their ecological and economic development in the production of ceramic bricks.

The utilization of waste materials used for production of energy-saving building materials used in passive housing is feasible. The proposed technologies of firing the bricks combine the feasibility to dispose of waste and to produce new type of bricks, fully environmentally friendly and safe. Heavy metal compounds present e.g. in wastewater sludge are permanently built into the structure of the formed aluminosilicate due to high temperature of the thermal synthesis process.

The use of waste results from the need of the waste-free management of waste materials, decreasing their number, reducing thermal and electrical energy consumption in incinerators, reducing the feasibility of dioxins occurrence in flue gas due to the higher temperature of ceramics heat treatment than during the combustion of the waste itself.

Developed technologies contribute to improving the environment due to the use of waste materials stored in specially designated areas such as wastewater treatment plants. This will allow for reduction of storage costs. It should be noted, however that the obtained products must comply with the European quality standard requirements for building materials, be in line with the policy of the EU directives implementation. The initiative taken by developing the concept of production of ceramic materials from raw materials derived from waste aims at raising the awareness with respect to energy saving and environmental protection, as well as implementation of environment-friendly technologies in traditional and passive housing.

Continuation of the research on the feasibility to use waste in building engineering will allow for promoting and implementing the best standards and practices with regard to energy efficiency and environmental protection. On the basis thereof there will be optimal energy efficient solutions developed in building engineering.

For wide production and utilization of bricks from waste materials, further research and development is needed, not only on the technical, economic and environmental aspects but also on standardization and public education (Zhang, 2013).

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