Chem. Chem. Technol., 2020,
Vol. 14, No. 1, pp. 88–92

Chemical Technology

MASONRY UNIT MANUFACTURING TECHNOLOGY USING POLYMERIC BINDER

***Olena Levytska*[1, ✉], *Olena Dolzhenkova*[1], *Oleksii Sichevyi*[1], *Larysa Dorhanova*[1]**

https://doi.org/10.23939/chcht14.01.088

Abstract. The paper discusses a problem of formation and search of efficient ways to recycle wastes generated by waste treatment plants, a proposed technology for their heat treatment and utilization of waste as a raw material component for the production of masonry units. High-density polyethylene is used as a binder.

Key words: recycling, sewage sludge, heating, melting, high-density polyethylene, forming.

1. Introduction

Waste management is well established in the developed countries and permits receiving useful products and energy from domestic household and industrial waste. At the same time, as people's needs increase, the production and consumption of plastic products have increased markedly, which leads to generation of large volumes of non-renewable wastes stored in organized or spontaneous landfills.

Therefore, the result of recycling polyethylene is useful products, including high-density polyethylene (HDPE) which is processed in a plastic lumber, trash receptacles, *etc*. [1]. In addition, polymers are used as catalysts, extractants, modifiers [2]. Also treated plastics are used in the cement matrix, and polymeric fibers can be used for strengthening cement [3].

HDPE is used as an aggregate for the production of concrete mixtures and the laboratory search discovered that the 28-day compressive strength of concrete containing 10 and 20 vol % of this type of plastic ranged from 22.997 to 26.617 MPa [4]. However, when the specified content of HDPE exceeded (20 vol %), the strength of concrete decreases, but the authors explain this not by the low strength of the plastic but by the low adhesion between it and the cement paste [4].

Oriyomi *et al*. [5] note not only about the possibility of using HDPE as an aggregate but also as a binder.

Wastes generated by wastewater treatment plants resulting from the treatment of domestic and industrial wastewater are also the subject for recycling. Werle *et al*. [6] point to the distribution of storage, the use of such wastes in agriculture and for necessity of the development of thermal methods for utilization of sewage sludge in Poland.

However, microbiological contamination and unstable chemical composition of such wastes are an obstacle to their use as fertilizers. Thus the authors of [7, 8] note that the dry matter content of wastes generated by wastewater treatment plants include 1–3 % of nitrogen, 1–2 % of phosphorus and 0.5–1.2 % of potassium. In addition, 100 g of the dry matter of sludge contains 0.04–0.22 g of manganese, 0.08–0.35 g of zinc and 0.02–0.35 g of copper. This fact is confirmed by chemical analyses of wastes from the Kamianske wastewater treatment plant which have high concentrations of Sr, Mn and Al and the content of Fe exceeds the existing standards [9].

In addition, Franus *et al*. [10] suggest the use of sewage sludge in manufacturing a light aggregate in the production of building materials, indicating that the presence of a significant amount of heavy metals in the waste makes it an effective raw material.

Taking into account the foregoing, the authors of this paper set the goal to develop an optimal technology of sewage sludge utilization from waste treatment facilities in the production of construction materials.

2. Experimental

2.1. Materials

Sewage sludge from one of the Kamianske municipal wastewater treatment facilities (Ukraine) was used in the experiments. The specified wastes are formed using the following methods of treatment of industrial and domestic sewage:

– mechanical treatment, when the pollutants that are visible to the eye delay on lattice and in sand traps, and settle in the primary settling tank,

[1] Oles Honchar Dnipro National University,
72, Gagarina Av., 49000 Dnipro, Ukraine
✉ *llevi@ukr.net*
© Levytska O., Dolzhenkova O., Sichevyi O., Dorhanova L., 2020

– biological treatment, which involves detention and processing of organic compounds and compounds of heavy metals with the help of active silt consisting of destructive microorganisms, the separation of silt and water in a secondary settling tank.

Wastes from sand traps and the primary settling tanks and dewatered on the secondary settling tank excess of active silt arrive at the sludge maps – places of waste storage. The latest ones occupy hundreds of hectares of fertile lands in Ukraine and pollute the soils around. Therefore, the issue of utilization of large amounts of sewage sludge is an important task for the technologists and ecologists of the country.

2.2. Preparation of the Samples

The technology of sewage sludge and HDPE waste recycling includes the following stages: processing and mixing of wastes, heating of the waste mixture to the melting point of HDPE, forming and cooling. The products will be masonry units that can be used in industrial construction.

Using a filter-press made for the experiments (Fig. 1), wet sewage sludge (98 %) was dehydrated to 75 % and its moisture content was lowered to 40 % during heat drying.

HDPE used in the experiment was ground manually to particle size 2, 4, 6, 8, 10, 12, 14, 16, 18 and 20 mm. In the course of the experiments, dependence of the heating time of raw mixtures on the particle size of ground polyethylene was tested (Fig. 2). The results of the experiment showed that the smaller fractions of HDPE were melting faster. In particular, when reducing the size of HDPE fractions from 40 to 20 mm, the heating time under the same conditions of supply and the amount of the heat will be reduced by almost half.

Decreasing the fineness of HDPE particles in the raw mixture increases its heating time, and, accordingly, the heat consumption, which is economically unprofitable. Therefore, it is better to use the smallest particles of HDPE.

The mixture of wastes was stirred for 1 min, loaded into an autoclave (Fig. 3), heated to 408 K, and then was stirred again for several minutes. The water vapor formed during the experiments escaped *via* the openings made on the device.

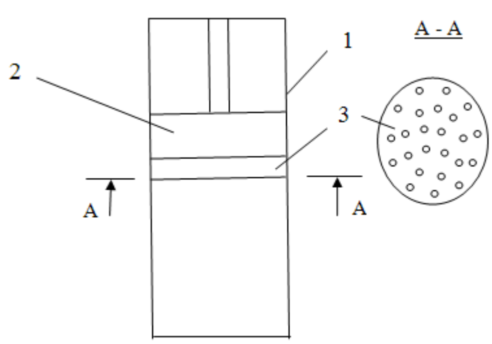

Fig. 1. Filter-press for dehydration of sewage sludge: filter-press housing (1); press (2) and screen (3)

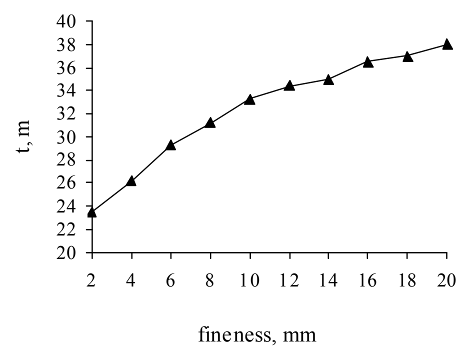

Fig. 2. Dependence of the heating time of raw mixture for making masonry units on the particle size of ground polyethylene

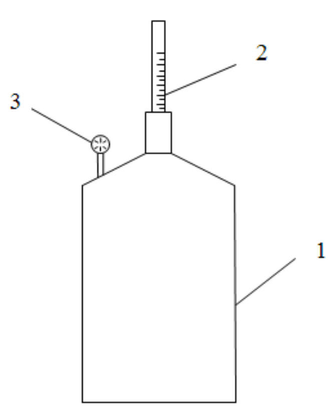

Fig. 3. Autoclave for heating sewage sludge and HDPE waste mixture: autoclave housing (1); thermometer (2) and barometer (3)

Fig. 4. Forming of samples of masonry units

Autoclave operation parameters:
– pressure 202.65 kPa,
– the initial temperature 298 K,
– the final temperature 408 K,
– total heat consumption 516 kJ/kg.
– time for heating, softening and full melting of the mixture 24 min.

The raw mixture ratio was determined experimentally. Thus an optimal appearance of the finished samples of construction products was reached with the volumetric ratio of sewage sludge to HDPE as (35–45):(55–65). Increasing the content of sewage sludge resulted in brittleness of the samples, and an increase in HDPE content is inexpedient from an economic point of view.

After being heated in an autoclave, the liquid hot mixture was poured into wooden cube moulds made for the experiments (Fig. 4). Samples of masonry units had a cuboid shape with a size of 70 mm.

Masonry units, made from sewage sludges and HDPE wastes, were investigated for strength at compression and frost resistance, and their average density was determined.

2.3. Analysis Methods

The average density was determined according to [11]: the samples of the masonry units were dried to a constant weight, the mass and volume of the samples were determined and the average density ρ_s, kg/m^3, as the ratio of the sample mass to its volume was calculated. Herewith three parallel samples were made and research results were averaged.

Frost resistance of samples of construction products was determined according to [11]: 20 samples with 70 mm faces were made, samples were filled with water and frozen and then were thawed. The frost resistance was estimated for the loss of the samples mass dried after thawing.

The strength at compression of building materials samples was determined according to [12]: samples of masonry units with 70 mm faces were prepared, samples were placed in the center of the bottom plate of the press, pressed with the top plate, reaching the growth of the load continuously and uniformly at a rate which provided an increase of the value of the calculated voltage in the masonry unit until its complete destruction within (0.6 ± 0.4) MPa/s. The strength of the compression of the masonry unit sample was determined.

3. Results and Discussion

Taking into account the above, as well as the experimental laboratory studies of wastes which are shown in Tables 1 and 2 [9], used by the authors in this paper, it should be noted about the presence of metal compounds in the sewage sludge. The largest content is made up of iron and aluminum compounds. In addition, sewage sludge may contain pathogenic microorganisms. Therefore, the usage of thermal processing methods is necessary.

Table 1

The content of chemicals in the waste products of the right-bank sewage treatment facilities of the city of Kamyanske, g/kg [9]

P_2O_5	CaO	MgO	K_2O	Na_2O	N_{total}
22.5	75	7.5	5	1.5	28

Table 2

The content of metals in the waste products of the right-bank sewage treatment facilities of Kamyanske, mg/kg [9]

Metal	Actual content	Standarts for the waste [15]	Metal	Actual content	Standarts for the waste [15]
Ba	1000	n/d	Sr	150	300
Cr	100	750	Mn	1000	2000
Pb	70	750	Bi	2	n/d
Sn	5	n/d	Nb	10	n/d
Ga	10	n/d	Ag	3	n/d
Ni	30	200	Al	10^5	n/d
Zn	300	2500	Fe	10^5	$2.5 \cdot 10^4$
Cd	3	30	Cu	50	1500
Co	7	100	V	20	n/d
Ti	500	n/d	Mo	2	n/d

Note: n/d – the value was not determined

The greater part of the cement clinker on the chemical composition is calcium oxide. Also, cement clinkers have in their composition compounds of magnesium (alite), potassium and sodium (aluminate phase). Phosphates and nitrogen compounds are non-typical components of building materials. Phosphates significantly reduce the heat of portland cement [13]. Nitrates of potassium, sodium and ammonium are slowing down the periods of cement stubbing [14].

Wastewater treatment plants, depending on the type of industrial enterprises that send their wastewater to the wastewater treatment plant, can contain large amounts of metals. Considering that in the eastern region of Ukraine there are chemical, metallurgical, machine-building and mining enterprises, wastes from the treatment facilities contain compounds of various metals, but the established standarts are exceeded by the content of the iron compounds. At the same time, iron-containing materials are used in construction and do not pose a threat to people and the environment.

HDPE wastes were also examined. It was taken into account that HDPE, when heated above 403–413 K, can pollute the atmosphere with such volatile pollutants as formaldehyde, organic acids, carbon monoxide, *etc*.

The technology of making masonry units is based on the property of HDPE to melt at relatively low temperatures and stiffen when these temperatures are dropping. All the components of the future building materials are heated simultaneously, which contributes to the reducing of the cost of energy resources for the process. After mixing and heating, small fractions of the sewage sludge blend with the melted masses of HDPE. Depending on the sewage sludge and HDPE waste ratio, pasty suspensions are formed and are used as a raw material for making masonry units.

A flow diagram illustrating the masonry unit production process is shown in Fig. 5.

The primary task in preparing raw materials components is the dewatering of sewage sludge. For this purpose mechanical methods of o sewage sludge processing is being introduced at the treatment plants today. The most popular and economically feasible among them are filter presses and centrifuges. However, centrifuges are more energy-consuming than filter presses. Therefore, the latest are recommended for using.

Sewage sludge (1) is dehydrated in the filter-press (4) and, together with ground HDPE wastes is fed to the mixer (7). The mixture (8) then is loaded into the melting and heating apparatus (9), heated to a melting point of HDPE and stirred again. The melted mixture of sewage sludge and HDPE (10) is poured into the vibropress (11) and formed into masonry units. Equipment for the formation of masonry units should be made from materials which are resistant to high temperatures. Standart size of masonry units which can be produced using this technology is 390:190:188 mm.

For the manufacture of masonry units from wastes, the raw material is purchased partly, which is the cost of its acquisition, and is partially recycled – when the waste-making enterprise pays the money for its utilization. Thus, an enterprise that produces construction products receives profits. In this case, wastes from treatment plants will bring profit, but the wastes of polyethylene today are sold as raw materials.

To determine qualitative characteristics of the masonry units, 3 parallel studies were conducted and their results were averaged. The obtained values of qualitative characteristics of masonry units are shown in the comparison with standard values and are given in Table 3.

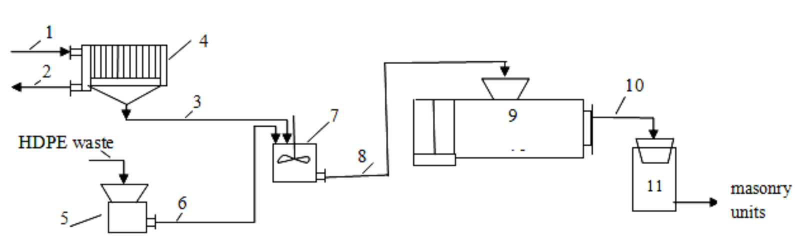

Fig. 5. Flow diagram of the masonry unit production: sewage sludge containing about 98 % water (1); wastewater that returns for treatment (2); dehydrated sewage sludge (3); filter-press (4); mechanical grinder (5); ground HDPE wastes (6); mixer (7); mixture of sewage sludge and ground HDPE wastes (8); melting and heating apparatus (9); mixture of melted HDPE and heated sewage wastes (10); vibropress (11)

Table 3

Qualitative characteristics of masonry units made using sewage sludge

Qualitative characteristic	Units with sewage sludge:HDPE ratio, wt/wt (v/v in brackets)		Standard [16]
	35:65 (22:78)	45:55 (28:72)	
Colour	black	black	–
Density, kg/m^3	1224	1230	–
Strength, MPa	7.4	7.5	2.5–15.0
Frost resistance	F30	F30	F15–100

Thus, by their compressive strength and frost resistance, the samples of construction products produced during the experiments comply with the applicable regulatory requirements and are recommended for use in industrial construction. Masonry units are recommended for laying walls of industrial installations, warehouses, storage chambers, arrangement of waste storage places, construction of garages and other buildings, which do not provide for the permanent residence of people, animals and the location of food.

Expenditure on raw materials for production, electricity and water, wages, rent of land for the production and storage of raw materials and products, transportation of raw materials, laboratory researches of quality of raw materials and manufactured products may be attributed to the current expenses, which will be spent on the implementation of masonry units manufacturing technologies.

4. Conclusions

An increase in the comprehensive strength of masonry units due to addition of sewage sludge is expected because it contains such compounds of high-strength metals as Al having a strength up to 88 MPa [17] and Fe having a strength up to 210 MPa [18]. Thus the technology of masonry unit production using the sewage sludge and HDPE wastes makes it posssible not only to dispose of generated wastes, but also to receive competitive building products – masonry units - which are recommended for use in industrial construction.

References

[1] Napier T.: Construction Waste Management. https://www.wbdg.org/resources/construction-waste-management
[2] Khodakarami M., Alagha L.: Polym-Plast. Technol., 2017, **56**, 2019. https://doi.org/10.1080/03602559.2017.1298800
[3] Cousins K.: Polymers in Building and Construction. ChemTec Publishing, 2002.
[4] Rahim N., Salehuddin S., Ibrahim N. *et al.*: Adv. Mater. Res., 2013, **701**, 265. doi:10.4028/www.scientific.net/AMR.701.265
[5] Okeyinka O., Oloke D., Khatib J.: Int. J. Civil Environ. Eng., 2015, **9**, 1570.
[6] Werle S., Wilk R.: Renew. Energ., 2010, **35**, 1914. https://doi.org/10.1016/j.renene.2010.01.019
[7] Shevchuk V., Chebot□ko K., Razgulyayev V.: Biotekhnolohiya Oderzhannya Orhanomineral□nykh Dobryv iz Vtorynnoyi Syrovyny. EkoBioTekh, Kyiv 2001.
[8] Likhachova A., Beskostaya L., Shybeka L.: Tezy dopovidey Mizhnarodnoyi naukovo-tekhnichnoyi konferentsiyi "Suchasni problemy nano-, enerho- ta resursozberihayuchykh i ekolohichno oriyentovanykh khimichnykh tekhnolohiy". Ukraine, Kharkiv 2010, 310.
[9] Levytskaya Ye.: Visnyk Nats. Tekhn. Univ. "KPI", 2012, **63**, 67.
[10] Franus M., Barnat-Hunek D., Wdowin M.: Environ. Monit. Assess., 2016, **188**, 10. https://doi.org/10.1007/s10661-015-5010-8
[11] Metody vyznachennya vodopohlynannya, hustyny i morozostiykosti budivel□nykh materialiv i vyrobiv. DSTU B V.2.7-42-97, Kyiv, Derkommistobuduvannya Ukrainy, 1997, 19.
[12] Materialy stinovi. Metody vyznachennya hranyts□ mitsnosti pry stysku i zhyni. DSTU B V.2.7-248:2011, Kyiv, Minrehion Ukrainy, 2012, 18.
[13] Dvorkin L., Dvorkin O.: Stroitelnyie Vyazhuschie Materialy. Infra-Inzheneriya, Moskva 2011.
[14] http://chemtech-bayern.com.ua/uk/statti/168.
[15] http://search.ligazakon.ua/l_doc2.nsf/link1/REG6691.html
[16] http://online.budstandart.com/ua/catalog/doc-page?id_doc=25433
[17] http://metmk.com.ua/113spr_alum.php
[18] https://uk.wikipedia.org/wiki/Zalizo

Received: May 14, 2018 / Revised: May 29, 2018 / Accepted: October 2018

ТЕХНОЛОГІЯ ВИГОТОВЛЕННЯ СТІНОВИХ КАМЕНІВ ІЗ ЗАСТОСУВАННЯМ ПОЛІМЕРНОГО ЗВ'ЯЗУЮЧОГО

Анотація. *Показана проблема утворення та пошуку шляхів утилізації відходів очисних споруд та запропонована технологія їх термічного оброблення та використання як сировинний компонент при виготовленні стінових каменів. Як зв'язуюче запропоновано використовувати поліетилен низького тиску.*

Ключові слова: *утилізація, відходи очисних споруд, нагрівання, розплавлення, поліетилен низького тиску, формування.*