Available online at www.sciencedirect.com
ScienceDirect
Ceramics International 39 (2013) 9179–9186
CERAMICS INTERNATIONAL
www.elsevier.com/locate/ceramint

Direct-utilization of sewage sludge to prepare split tiles

Jun Zhou[a,b,*], Tiantian Li[b], Qiuyu Zhang[b], Yanxin Wang[c], Zhu Shu[b]

[a]Engineering Research Center of Nano-Geomaterials of Ministry of Education, China University of Geosciences, 430074 Wuhan, PR China
[b]Faculty of Material Science and Chemistry, China University of Geosciences, 430074 Wuhan, PR China
[c]School of Environmental Studies, China University of Geosciences, 430074 Wuhan, PR China

Received 23 February 2013; received in revised form 1 May 2013; accepted 5 May 2013
Available online 13 May 2013

Abstract

As a type of solid waste with large quantities of pollutants, municipal sewage sludge (MSS) itself and its reclamation are becoming a growing concern of governments. In this paper, the direct-utilization of MSS to prepare split tiles is proposed and tested. Without any pretreatments such as thermokinetic drying, the crude MSS from domestic wastewater treatment plant is directly incorporated into the batch mixtures, and then wet ball-milled, filter-pressed, pug-milled, extrusion-formed, dried and fired to obtain split tiles. A series of formulation experiments and physical and chemical characterizations were carried out; the results show that the feasible maximum content of the crude MSS is as high as 60 wt%, and corresponding bending strength and water absorption of split tile samples fired at 1210 °C are 25.5 MPa and 1.14 wt% respectively. TCLP test reveals that the samples are environmentally compatible. The prospective industrial application of MSS to produce split tile will help to significantly reduce its environmental impacts.

Keywords: Sewage sludge; Split tile; Waste reclamation; Ceramic; Building material

1. Introduction

Municipal sewage sludge (MSS) is a kind of solid waste discharged by domestic wastewater treatment plants, and contains a great amount of pollutants such as organic contaminants, heavy metals, pathogenic microorganisms and so on, which easily lead to serious secondary environmental pollutions [1–4]. Therefore, much attention has been paid to the pollution controls of MSS worldwide, due to the growing social and environmental pressure [5–8]. Moreover, it is more significant to develop the recycling technologies of MSS while solving its environmental pollution. Several investigations in this field have been carried out, and the main technologies include composting [9,10], anaerobic digestion [11–13], combustion [14,15], thermolysis [16,17], producing building materials [18–20], and so on.

In terms of building materials, MSS is mainly utilized to produce cements [21,22], bricks [23,24], ceramic pellets [25,26] and ceramic tiles, of which the ceramic tile industry is the most potential technological activity sector to absorb solid wastes, due to large quantities of raw materials and final products used.

A large number of works on preparing ceramic tiles from MSS have been performed. Li et al. [27] applied dried MSS for the fabrication of ceramic tiles, and concluded that, with the increase of sludge content, the compressive strength of the ceramic tiles decreases rapidly and the bending strength increases slightly. Jordán et al. [28] utilized dried MSS in the manufacture of ceramic tiles and confirmed that the addition of MSS decreases the bending strength and increases the water absorption of the products, and further suggested that the amount of MSS added must be controlled. Monteiro et al. [19] assessed the utilization of MSS dried at 110 °C in the preparation of red ceramics and concluded that the incorporation of MSS up to 10 wt% will impact the technological properties of the products. Qi et al. [29] used MSS dried at 105 °C to prepare ultra-lightweight ceramics tiles, and revealed that the optimum addition of dried MSS is 20–30 wt% and the resulting samples are light, waterproof and

*Corresponding author at: China University of Geosciences, Engineering Research Center of Nano-Geomaterials of Ministry of Education, Faculty of Material Science and Chemical Engineering, No. 388 Lumo Road, Wuhan, Hubei 430074, PR China. Tel.: +86 13018015320; fax: +86 27 67883731.
E-mail addresses: zhoujun@cug.edu.cn, zhoujun198@126.com (J. Zhou).

0272-8842/$ - see front matter
http://dx.doi.org/10.1016/j.ceramint.2013.05.019

nontoxic. Besides, the residues from combusting sewage sludge were also reused to prepare ceramic tiles [30,31].

It can be noted from the above literatures that, owing to its high water content, MSS is firstly pre-dried and then reused and recycled, which would lead to high energy consumption and thus limit the industrial utilization of MSS in a large scale.

In this paper, a novel proposal on direct-utilization of crude MSS as the main raw material to prepare split tiles was designed and tested by the authors. Split tile is a kind of ceramic tile, generally used as a decorative building material mainly for the wall surface, which is produced generally by procedures such as wet ball-milling, filter-pressing, vacuum pug-milling, aging, extrusion-forming, drying and sintering [32,33].

In the manufacture of split tile, the batch mixture generally needs addition of fresh water for subsequent wet ball-milling. Therefore, the water from MSS can partially substitute for the fresh water, implying that the crude MSS with high water content may be directly incorporated into the mixture to produce the split tile. In this case, the dehydrating and/or drying pretreatment of MSS can be bypassed, so as to reduce the energy consumption and to save the corresponding cost, which is the key point and technological significance of this paper.

Besides, during firing the split tile, pathogenic bacteria and organic matters can be decomposed and detoxified [15,34], and the released bioenergy can be recovered [34,35]. Furthermore, the heavy metals from MSS can be effectively solidified in split tile bodies, like other ceramic materials [36–38].

In this research, the objective of our study is to probe the possibility of directly preparing split tile from crude MSS and the impacts of MSS on technological conditions, to investigate the feasible maximum proportion of MSS in split tile formulations, and to measure and evaluate the physical properties and environmental compatibility of the resulting split tile. The final purpose is to develop a novel technology of directly producing split tile from MSS.

2. Materials and methods

2.1. Raw materials

MSS from a domestic wastewater treatment plant in Wuhan City of Hubei Province, PR China, was used in this study. The MSS specimens were obtained in January, April, July and October, and their chemical compositions and water contents are given in Table 1. The ignition losses (IL) of MSS-April and MSS-October are comparable and close to the annual mean value. On the other hand, after deducting IL, the contents of inorganic matters of all specimens are similar to each other. So, the MSS-October specimens were used to prepare split tiles in this paper. In addition, the chemical compositions of supplementary raw materials are also given in Table 1.

In terms of the preparation of ceramic tiles, it can be seen in Table 1 that the chemical compositions of MSS are mainly SiO_2 and Al_2O_3, which are consistent with those of the traditional clayey raw materials for ceramic tiles. Besides, such melting constituents as MgO, K_2O and Na_2O present in MSS are beneficial to the sintering of split tile. However, some harmful impurities, for instance, Fe_2O_3, TiO_2 and CaO, could affect the firing behavior of split tile bodies, and especially large quantities of organics indicated by ignition loss (IL) could lead to relatively high shrinkage and porosity.

2.2. Preparation of split tiles

The flowchart of preparing split tile from crude MSS is shown in Fig. 1. The detailed procedures are as follows: (1) weighing the proportioned raw materials into batch mixtures according to the designed formulations shown in Table 2 and wet ball-milling them into slurries; (2) filter-pressing the slurries into filter cakes with a moisture content of 18–30 wt%; (3) vacuum pug-milling the filter cakes into mud-strips at the pressure of −0.09 MPa and then aging them for 24 h to homogenize their moistures; (4) extrusion-forming the mud-strips into wet green bodies with the size of 150 mm × 65 mm × 7 mm; (5) drying the wet green bodies at 110 °C in an oven, to obtain dry ones with a moisture content of 1–2 wt%; (6) firing the dry green bodies in an electric furnace following the heating procedure below: heating the bodies at a rate of 20 °C/min to 850 °C for 10 min to fully decompose organic matter, continually heating them at the same rate to different sintering temperatures varying from 1150 °C to 1230 °C for 20 min with a temperature interval of 20 °C, and finally obtaining MSS split tiles after cooling naturally.

Table 1
Chemical compositions and water contents of MSS samples and other raw materials (wt%).

Materials	Chemical compositions[a]									Water content
	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	K_2O	Na_2O	IL[b]	
MSS-January	34.95	11.17	4.26	0.88	5.07	1.55	1.65	1.13	37.24	90.96
MSS-April	36.19	12.20	5.87	0.31	4.13	0.98	2.37	0.58	34.52	86.32
MSS-July	38.01	13.75	4.73	0.26	4.53	2.13	1.39	0.67	32.09	85.47
MSS-October	36.40	12.05	5.16	0.69	3.97	1.31	2.01	0.49	35.40	87.01
Quartz	98.23	0.21	0.62	0.13	0.24	0.22	0.10	0.12	0.05	/
Feldspar	72.18	15.17	0.50	0.50	0.50	0.13	3.50	7.11	0.27	/
Kaolin	44.72	36.91	0.35	0.20	0.11	0.08	0.13	0.15	17.12	/

[a]All measured specimens were dried at 110 °C.
[b]IL: ignition loss.