Desalination and Water Treatment
www.deswater.com
doi: 10.1080/19443994.2015.1042055

57 (2016) 11411–11421
May

Taylor & Francis
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Preparation and characteristics of lightweight sludge ceramics by dehydrated sludge from dye intermediate processing wastewater treatment

Su-qing Wu[a,b,1], Yuan-feng Qi[a,b,1], Qin-yan Yue[b,*], Bao-yu Gao[b], Yue Gao[c], Chun-zhen Fan[a], Sheng-bing He[a]

[a]*School of Environmental Science and Engineering, Shanghai Jiaotong University, Shanghai 200240, P.R. China, emails: wusuqing@sjtu.edu.cn (S.-q. Wu), yuanfengq@qq.com (Y.-f. Qi), chunzhen0377@163.com (C.-z. Fan), heshengbing@sjtu.edu.cn (S.-b. He)*
[b]*Shandong Key Laboratory of Water Pollution Control and Resource Reuse, School of Environmental Science and Engineering, Shandong University, Jinan 250100, P.R. China, Tel. +86 531 88365258, Fax: +86 531 88364513; emails: qyyue@sdu.edu.cn, qyyue58@aliyun.com (Q-y. Yue), bygao@sdu.edu.cn (B.-y. Gao)*
[c]*School of Environment, Tsinghua University, Beijing 100084, P.R. China, email: gaoyue0322@126.com*

Received 5 June 2014; Accepted 9 April 2015

ABSTRACT

Lightweight sludge ceramics (LSC) manufactured by two kinds of clay and dehydrated sludge from 4,4´-diaminostilbene-2,2´-disulfonic acid (DSD acid) processing wastewater treatment (DSD sludge) were studied for the sludge treatment. The raw pellets were preheated at 400℃ for 15.0 min and sintered at 1,150℃ for 8.0 min, which was beneficial to produce LSC. The optimum DSD sludge addition rate was determined by the physical properties (bulk density, water absorption, grain density, and expansion ratio), and then toxic metal leaching properties and microstructure properties were characterized. The results indicated that clay with high content of Fe_2O_3 might be more suitable for ceramics preparation, lower bulk (627.00 kg m^{-3}), and grain density (1,280.00 kg m^{-3}), and higher expansion ratio (18.80 v/v%) could be obtained with the optimum DSD sludge addition rate of approximately 50.0 wt%. Toxic metal leaching test showed that LSC was nontoxic and would not cause secondary pollution to water environment when applied as fillers, and the sintered ceramics had rough surface and porous interior according to microstructure analysis. Therefore, LSC prepared in this study might be utilized as biological media in wastewater treatment, which could turn hazardous solid waste (DSD sludge) into useful materials.

Keywords: Dehydrated sludge; Lightweight; Ceramics; DSD acid processing wastewater

1. Introduction

As an important intermediate during production of fluorescent whitening agents, direct dyes, and fungicides [1–3], 4,4´-diaminostilbene-2,2´-disulfonic acid (DSD acid) is synthesized from p-nitrotoluene via sulfonation, nitration, oxidation, condensation, and reduction [4]. Due to complicated production process and low utilization ratio of raw materials, wastewater from DSD acid manufacturing process is usually characterized by high concentrations of aromatic

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*Corresponding author.

[1] The first two authors equally contributed.

compounds substituted derivatives and high organism toxicity [5]. Therefore, DSD acid manufacturing wastewater has been highly polluted, and more and more wastewater is generated as DSD acid manufacturing industry develops.

Sludge, a by-product from primary (physical and/or chemical), secondary (biological), and tertiary treatments, is abundantly generated with large quantities of DSD acid manufacturing wastewater [6,7]. Moreover, sludge usually contains pollutants (organic matters, heavy metals, etc.) and unstable pathogen, which are harmful to human health and environment [8–13]. Conventional sewage sludge treatments mainly involve incineration, landfilling, composting and land application, etc., which are usually uneconomical, unsafe, and unsanitary [14,15]. Therefore, it is significant to develop ecofriendly and economical methods to prevent secondary pollution from sludge and to convert sludge into useful resource.

Ceramic, as a kind of novel materials, has been widely applied in construction industry, chemical industry, metallurgy, agriculture, and environmental protection [16–20]. Due to limited natural resource and a great demand for municipal engineering materials, many researchers have studied preparation of ceramics from sludge. Suzuki utilized sewage sludge ash to prepare glass-ceramic [21]. Merino studied the possibility of utilizing sludge ashes obtained from wastewater treatment plant to prepare lightweight ceramics [22,23]. Mun developed lightweight ceramics with two-stage sintering process [24]. Cheeseman and Vird sintered lightweight ceramics in rotary electric tube furnace [25]. Little and Adell utilized coal fly ash and metal finishing wastes as raw materials for preparing ceramic materials [26]. Therefore, sludge should be used as raw materials for preparing ceramics, in order to prevent secondary pollution from sludge and turn it into useful resource.

In this research, there were three objectives as follows:

1. The possibility of two kinds of clay and dehydrated sludge from (DSD acid) manufacturing process wastewater treatment as raw materials was investigated for preparing lightweight sludge ceramics (LSC).
2. The optimum ratio of clay to dehydrated sludge (by mass) was determined by the physical properties (bulk density, water absorption, grain density, and expansion ratio).
3. The utilization of two different kinds of clay as raw materials for LSC preparation was compared for determining more suitable clay.

2. Materials and methods

2.1. Pretreatment of raw materials

Two kinds of clay and dried sewage sludge from DSD acid manufacturing wastewater treatment (DSD sludge) were utilized as raw materials for preparation of (LSC). The clays (JN clay and CZ clay) were obtained from Jinan City (Shandong Province, China) and Cangzhou City (Hebei Province, China), respectively. DSD sludge was obtained from the wastewater treatment plant of a DSD acid manufacturing enterprise in Cangzhou City. DSD sludge and clays were dried in oven at 105℃ for 4.0 h, crushed in a ball mill, sieved (the diameter of the sieve mesh was 0.154 mm), and preserved until being used in polyethylene vessels to avoid humidification.

2.2. Property test of raw materials

Energy dispersive X-ray detector (DZ10-100 X-ray fluorescence spectrometer) and element analyzer (Elementar Vario EL III) were utilized to determine the chemical components of raw materials, and the mineral components of clays were measured by D/max-ra X-ray diffractometer (XRD, Shimadzu XRD-6100). Before the thermal property test, raw materials were stored in a porcelain dish at 25.0℃ for 24.0 h in air (air humidity was 50.0%). The thermal properties of raw materials were analyzed with thermogravimetric analysis (TGA) and differential scanning calorimetry (DSC). SDT Q600 equipment was utilized and the raw materials were heated in air at 10.0℃ min^{-1} in the range from 22.0 to 1,100℃. DSC and TGA diagram were obtained by SDT Q600 equipment at the same time.

2.3. Preparation and sintering of LSC

Nine mass ratios of clay to DSD sludge (10:0, 9:1, 8:2, 7:3, 6:4, 5:5, 4:6, 3:7, and 2:8) were selected throughout the preparation process. The raw pellets were thermally treated according to the following procedures as shown in Fig. 1.

Step 1: Dosage, mixing, and drying. DSD sludge and clay (JN clay and CZ clay, respectively) were stirred in a dry powder stirrer (B10-20B, made in China) for about 10 min. After mixing completely, the mixture was poured into a pelletizer (DZ-20 equipment) to produce raw pellets (about 7.00 wt% of water was added in this process). Then the raw pellets selected for the following thermal treatment were sifted by two sieves (the diameters of meshes were 5.00 mm and

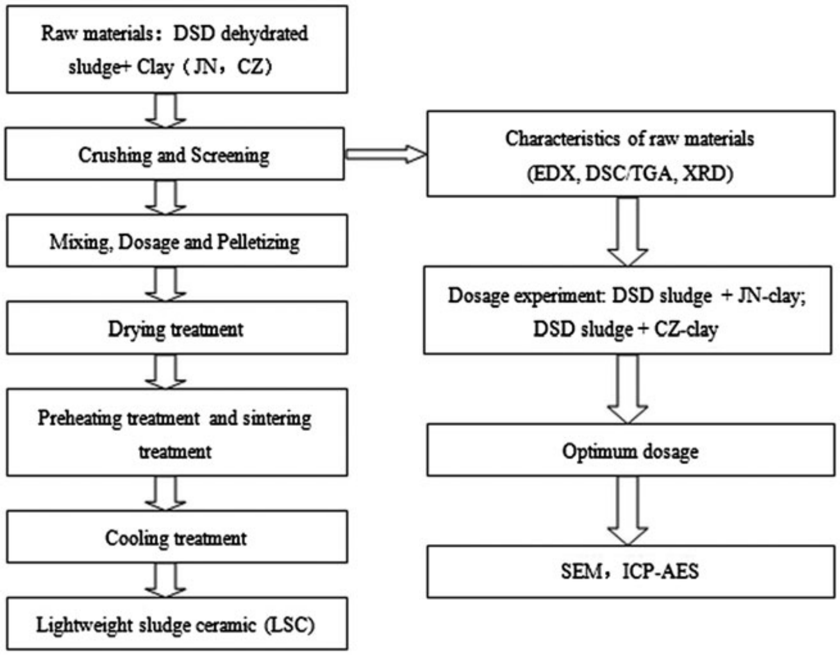

Fig. 1. Flow chart for preparation of LSC.

6.00 mm, respectively). The raw pellets were stored in draught cupboard at room temperature (22.0℃) for 24.0 h before the thermal treatment.

Step 2: Preheating and sintering treatment. According to our previous study [27], the dried raw pellets, which were kept in porcelainous crucibles, were settled in muffle and preheated at 400℃ for 15.0 min. After the preheating treatment, the pellets were rapidly transferred into electric tube rotary furnace (KSY-4D-16, made in China) and sintered at 1,150℃ for 8.0 min in anoxic condition. The pellets were placed in the center of the heated zone.

Step 3: Cooling treatment. After the sintering process, the sintered pellets were stored in draught cupboard until they have been cooled down to room temperature (22.0℃) [27].

2.4. Characterization of LSC

The physical properties of LSC (bulk density, grain density, water absorption, and expansion ratio) were adopted to characterize LSC. Water absorption and bulk density were determined according to the national standard (GB/T 17431.2-2010) [28]. LSC were settled in an exsiccator at 105℃ for 4.0 h before the tests. After the drying process, 100.0 g of dried ceramics was put in a measuring cylinder (500 mL) and leveled completely, to determine the bulk volume of dried ceramics. Then 200 mL of water was added into the measuring cylinder and the pellets were covered completely. After 1.0 h, a dry towel was utilized to dry the surface of the wet pellets, and the saturated wet ceramics were weighed. Grain density was determined by the dry mass (M_{dry}) and the volume of the sintered ceramics (V_{grain}). Individual grain density was calculated according to the Archimedes' principle. The above-mentioned physical properties were obtained as follows:

$$\text{Bulk density } = \frac{\text{mass of ceramic bodies}}{\text{bulk volume of ceramic bodies}}\,\text{kg m}^{-3} \tag{1}$$

$$\text{Grain density } = \frac{\text{mass of ceramic bodies}}{\text{volume of ceramic bodies}}\,\text{kg m}^{-3} \tag{2}$$

$$\text{Water absorption } = \frac{\text{1h saturated mass of ceramic bodies} - \text{mass of dry ceramic bodies}}{\text{mass of dry ceramic bodies}} \times 100\% \tag{3}$$

$$\text{Expansion ratio} = \frac{\text{volume of sintered ceramic bodies} - \text{volume of raw pellets bodies}}{\text{volume of raw pellets bodies}} \times 100\% \quad (4)$$

LSC prepared in the optimum conditions were examined by scanning electron microscopy (Hitachi S-520) both on the surface and in the cross section (Au coated).

About 1,000.00 g of LSC prepared in the optimum conditions was soaked in 1.00 L of hydrochloric acid (0.20 mol L^{-1}; HCl: $\rho = 1.19$ g mL^{-1} Guaranteed Reagent) for 24.0 h. About 1.00 mL of leach solution obtained from the supernatant was collected for leaching test of the toxic metal elements. Toxic metal concentrations (Cu, Zn, Pb, Cr, Cd, Hg, Ba, Ni, and As) of 1,000.00 g of LSC were determined by ICP-AES (IRIS Intrepid II XSP equipment) and compared with the national standard (GB 5085.3-2007, China) [29].

3. Results and discussion

3.1. Chemical component analysis of raw materials

The chemical components of raw materials are shown in Tables 1 and 2. It can be seen that the main inorganic components of JN clay were SiO_2 (67.03%) and Al_2O_3 (13.99%) followed by CaO (1.87%), Fe_2O_3 (6.47%), K_2O (2.61%), MgO (2.08%), and Na_2O (2.33%). The major inorganic components of CZ clay were SiO_2 (60.97%) and Al_2O_3 (16.08%) followed by CaO (4.37%), Fe_2O_3 (7.68%), K_2O (2.42%), MgO (2.95%), Na_2O (2.23%), and TiO_2 (0.65%). The results revealed that the main inorganic components of JN clay (SiO_2 and Al_2O_3) was the same as CZ clay; the content of CaO in CZ clay (4.37%) was higher than that of JN clay (1.87%), and CZ clay contained very little TiO_2 (0.65%), while JN clay did not contain TiO_2.

Table 1 also shows that the major inorganic components of DSD sludge were SiO_2 (15.02%), CaO (38.63%), Fe_2O_3 (14.88%), and Al_2O_3 (12.25%) followed by K_2O (0.11%), MgO (3.04%), Na_2O (5.33%), and TiO_2 (0.49%). It can be seen that the content of CaO in DSD sludge was very high (38.63%). The reason may be that a great quantity of calcium hydroxide was added to adjust pH of wastewater during the whole wastewater treatment. The contents of Fe_2O_3 (14.88%) and Al_2O_3 (12.25%) were also high, maybe because flocculating agent was added during the whole wastewater treatment. Besides, Table 2 reveals that the organic components of DSD sludge and the main organic components included carbon (28.64%), hydrogen (4.03%), nitrogen (3.96%), and oxygen (22.23%). The influences of chemical components of raw materials on sintering LSC are discussed in Section 3.4.

Table 2
Elemental analysis of DSD sludge (wt%, in dry basis)

Material	C	H	N	S	O	Ash
DSD sludge	28.64	4.03	3.96	0.95	22.23	40.19

3.2. Mineral components of clays

The mineral components of clays determined by XRD analysis are shown in Fig. 2. It could be noted that the major peaks of JN clay samples were possibly attributed to quartz (SiO_2), and the minor peaks were probably attributed to kalisilite ($KAlSiO_4$) and fenaksite ($KNaFe(Si_4O_{10})$). The major peaks of CZ clay might be attributed to quartz (SiO_2), and the minor peaks were probably attributed to anorthoclase ($KAlSi_3O_8$) and brinrobertsite ($(Na, K, Ca)_x(Al, Fe, Mg)_4(Si, Al)_8O_{20}(OH)_4 \cdot n(H_2O)$ [$x = 0.35$, $n = 3.54$]). The results also revealed that there were different mineral components between the two kinds of clay, and these different mineral components might lead to different effects when they were added to sinter ceramics.

Table 1
The chemical components of raw materials

Material	SiO_2	CaO	Fe_2O_3	K_2O	Al_2O_3	MgO	Na_2O	TiO_2	Other
JN clay/wt%	67.03	1.87	6.47	2.61	13.99	2.08	2.33	–	3.62
CZ clay/wt%	60.97	4.37	7.68	2.42	16.08	2.95	2.23	0.65	2.65
DSD sludge/wt%	15.02	38.63	14.88	0.11	12.25	3.04	5.33	0.49	10.25

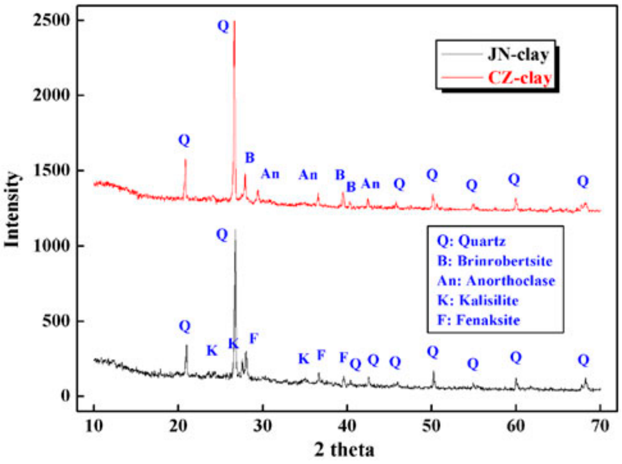

Fig. 2. Mineral components analysis of clays (XRD).

3.3. Thermal analysis of raw materials

The thermal analysis of raw materials (DSC/TGA) is shown in Fig. 3. Fig. 3(a) shows the thermal analysis of JN clay; TGA curve reveals that a weight loss (about 11.47%) occurred from 30.62 to 554.55℃, possibly due to the emission of absorbed water and interstitial water and the combustion of organic matter. From 554.55 to 681.89℃, there was a sharp drop in weight and the weight loss reached approximately 12.60%, probably due to the emission of structural water and the combustion of organic matter. As DSC curve shows in Fig. 3(a), there is an endothermic peak at about 657.62℃, possibly attributed to the emission of structural water, and two exothermic peaks existed at about 400.0℃ and 678.40℃, probably attributed to the combustion of organic matter.

The thermal analysis of CZ clay is shown in Fig. 3(b); the results of TGA curve indicated that there was a weight loss (approximately 0.76%) from 24.38 to 142.43℃ and the following weight loss (approximately 5.71%) happened from 142.43 to 702.40℃, possibly due to the emission of absorbed water and the emission of interstitial water and structural water, respectively. The results of DSC curve revealed that two endothermic peaks existed at about 626.17 and 822.54℃, respectively. The former was possibly attributed to the emission of interstitial water and structural water, and the latter was probably attributed to the decomposition of brinrobertsite or the melting of alkali metal oxide.

Fig. 3(c) shows the analysis of DSD sludge; the results of TGA curve indicate that a weight loss (about 11.60%) happened from 30.16 to 627.17℃, possibly attributed to the emission of absorbed water and interstitial water and the combustion of organic matter. The following weight loss (about 11.93%) happened from 627.17 to 736.31℃, probably due to the emission of structural water and the combustion of organic matter. DSC curve revealed that an endothermic peak existed at about 702.92℃, possibly due to the emission of structural water, and two exothermic peaks happened at about 400 and 726.02℃ respectively, probably attributed to the combustion of organic matter.

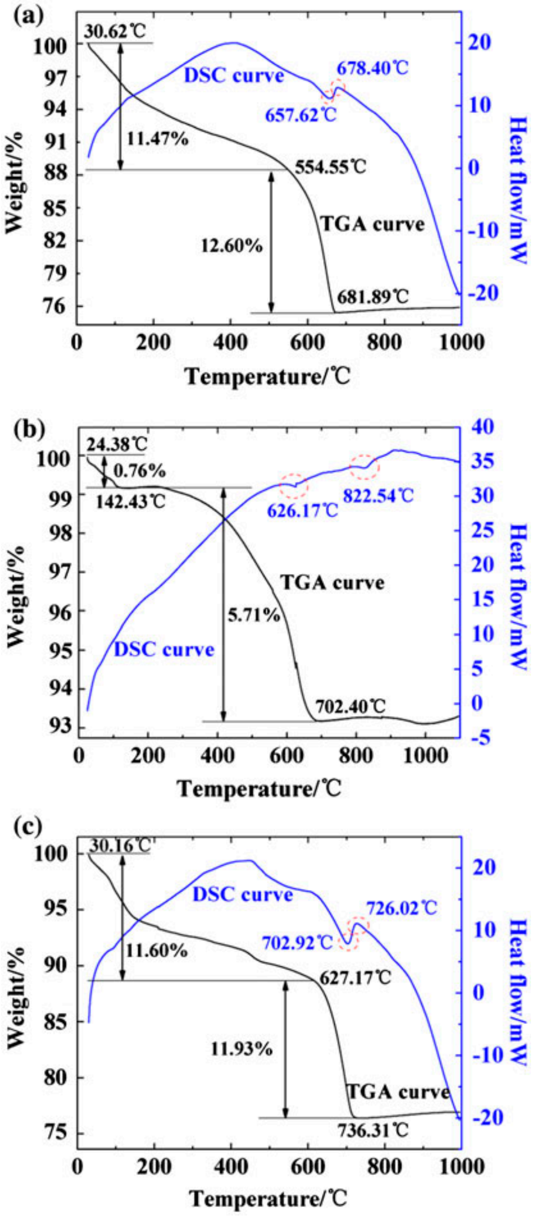

Fig. 3. Thermal analysis of raw materials (DSC/TGA). (a) JN clay; (b) CZ clay; (c) DSD sludge.

3.4. Preparation of LSC

3.4.1. Utilization of CZ clay for preparing LSC

It was well known that the chemical components of raw materials could be classified into three groups [30]: (1) the glassy phases, mainly containing SiO_2 and Al_2O_3, which formed the framework and surfaces of ceramics, and the mass ratio of the glassy phases was about 75.0%; (2) flux, mainly containing alkali metal oxide and alkaline earth metal (CaO, Na_2O, K_2O, MgO, etc.), which lowered the melting point; and (3) the gaseous components, which generated gases (oxygen, O_2) and bloated the ceramic bodies in the sintering process at high temperature (about 1,000–1,150˚C), mainly containing carbon and Fe_2O_3 [27].

Fig. 4 shows the physical properties of LSC (bulk density, grain density, water absorption, and expansion ratio) prepared from CZ clay and DSD sludge. The results indicated that the variation tendency of bulk density was similar to grain density as clay–sludge ratio (C:S) decreased, and expansion ratio represents the opposite tendency. It could be deduced from Tables 1 and 2 that the gaseous components of the raw pellets were mainly derived from two kinds of materials, including expansion materials (organic matter in DSD sludge, playing a major role in bloating process) and expansion components (Fe_2O_3 in clay and sludge, generating O_2 at high temperature (>1,100˚C)) [16,31]. Bulk density and grain density of the ceramics decreased gradually as DSD sludge addition rate (by mass) increased from 0 to 50.0%. It was likely that the gaseous components (organic matter and Fe_2O_3) increased accordingly by increasing DSD sludge addition rate. Thus, more gases inside the ceramics generated and the expansion force also increased rapidly, leading to the increase of expansion ratio of the ceramics. Meanwhile, the ceramics volume increased rapidly as expansion ratio increased, resulting in the decrease of bulk density and grain density. Additionally, the ceramics would be bloated at high temperature and the thickness of shell of the pellets surface decreased accordingly due to the generated gases inside. More gases would be generated inside the ceramics due to the increase of DSD sludge addition rate, and shells of the ceramics surface will not able to cover the gases at this moment. [27,31], resulting in the escape of some gases from the shells and the increase of water absorption.

When DSD sludge addition rate (by mass) increased from 50.0 to 80.0%, bulk density and grain density of the ceramics increased gradually. It was likely that when DSD sludge addition rate was too high, large quantities of gases were generated inside the ceramics. Meanwhile, the content of CaO (the main flux of the ceramics) increased rapidly with the increase of DSD sludge addition rate. Thus, shells of the ceramics surface were more easily melt and more gases will be able to easily escape from inside of the ceramics. Then the ceramics began to shrink, leading to the decrease of the expansion ratio and the increase of bulk density and grain density. However, shells of the pellets surface might crack as large quantities of gases escaped from inside of the ceramics, and water can easily enter the ceramics, resulting in the small variation of water absorption.

Overall, when CZ clay and DSD sludge were utilized as raw materials for preparing LSC, the optimum addition of DSD sludge should be approximately 50.0 wt%, in order to obtain lower bulk density (627 kg m^{-3}) and grain density (1,280 kg m^{-3}), and higher expansion ratio (18.8 v/v%).

3.4.2. Utilization of JN clay for preparing LSC

The physical properties of LSC (bulk density, grain density, water absorption, and expansion ratio) prepared from JN clay and DSD sludge are shown in Fig. 5. The results revealed that bulk density and grain density of the ceramics decreased as the clay–sludge ratio (C:S) decreased from 10:0 to 5:5, and when C:S decreased from 5:5 to 2:8, bulk density and grain density increased gradually, and then expansion ratio represent the opposite tendency. Water absorption increased gradually as DSD sludge addition rate increased from 0 to 50.0%, and remained almost constant at high DSD sludge addition rate (>50.0%).

The interpretation for the variation of the properties was similar to the CZ clay–DSD sludge system, where CZ clay and DSD sludge were used as raw materials for preparing LSC. When DSD sludge addition rate increased from 0 to 50.0%, the gaseous components (organic matter and Fe_2O_3) increased accordingly, leading to the increase of gases generated inside the ceramics, resulting in the increase of expansion ratio, and a decrease in bulk density and grain density. Meanwhile, the thickness of shell on the ceramics surface decreased due to an increase in the gases generated inside by increasing DSD sludge addition rate, and water which easily enters the ceramics, leading to the increase of water absorption. However, large quantities of gases were generated inside the ceramics due to high DSD sludge addition rate (>50.0%), meanwhile shells of the ceramics surface were more easily melt, probably attributed to an increase in CaO content by increasing DSD sludge addition rate. Therefore, large quantities of gases evaporated from inside of the ceramics, resulting in the increase of bulk density, grain density, and water absorption.

Overall, 50.0 wt% of DSD sludge addition rate was a better choice than other rates when JN clay was added for preparing LSC, and lower bulk density (805 kg m^{-3}) and grain density (1,449 kg m^{-3}) and higher expansion ratio (15.6 v/v%) could be obtained.

3.4.3. Comparison between CZ clay and JN clay as raw materials respectively

Figs. 4 and 5 show the physical properties of LSC prepared from CZ clay and JN clay respectively. The results indicated that bulk density and grain density of LSC in CZ clay–DSD sludge system (CZ clay and DSD sludge were used as raw materials) were all lower than that in JN clay–DSD sludge system (JN clay and DSD sludge were used as raw materials), and expansion ratio of LSC in CZ clay–DSD sludge system was higher than that in JN clay–DSD sludge system. It can be deduced that the content of Fe_2O_3 in CZ clay was higher than that in JN clay, which could release O_2 at high temperature (about 1,000–1,150℃), and carbon could rapidly react with O_2 to generate carbon monoxide (CO) and carbon dioxide (CO_2), which were investigated in our previous work [27]. When other conditions including preheating temperature and time, sintering temperature and time, and DSD sludge addition rate (approximately 50.0 wt%) were all the same in the two systems, more gases were generated in CZ clay–DSD sludge system. Moreover, the content of CaO (belonging to flux, which could lower the melting point) in CZ clay–DSD sludge system was also higher than that in JN clay–DSD sludge system, and shells of the ceramics surface in CZ clay–DSD sludge system were more easily melt. Therefore, under the same conditions, the ceramics in CZ clay–DSD sludge system were more easily bloated than that in JN clay–DSD sludge system, and lower bulk and grain density and higher expansion ratio of LSC could be obtained in CZ clay–DSD sludge system accordingly.

Overall, the above comparison revealed that CZ clay was a more suitable choice as raw material for preparing LSC when DSD sludge was added.

3.5. Toxic metal leaching and microstructure analysis of LSC

3.5.1. Toxic metal leaching test of DSD sludge and LSC

Table 3 showed the results of toxic metal leaching test of DSD sludge and LSC prepared in the optimum conditions (the mass ratio of CZ clay to DSD sludge was 1:1), revealing that all the nine toxic metal (Cu, Zn, Pb, Cr, Cd, Hg, Ba, Ni, and As) contents in lixivium of LSC did not exceed the limits of the national

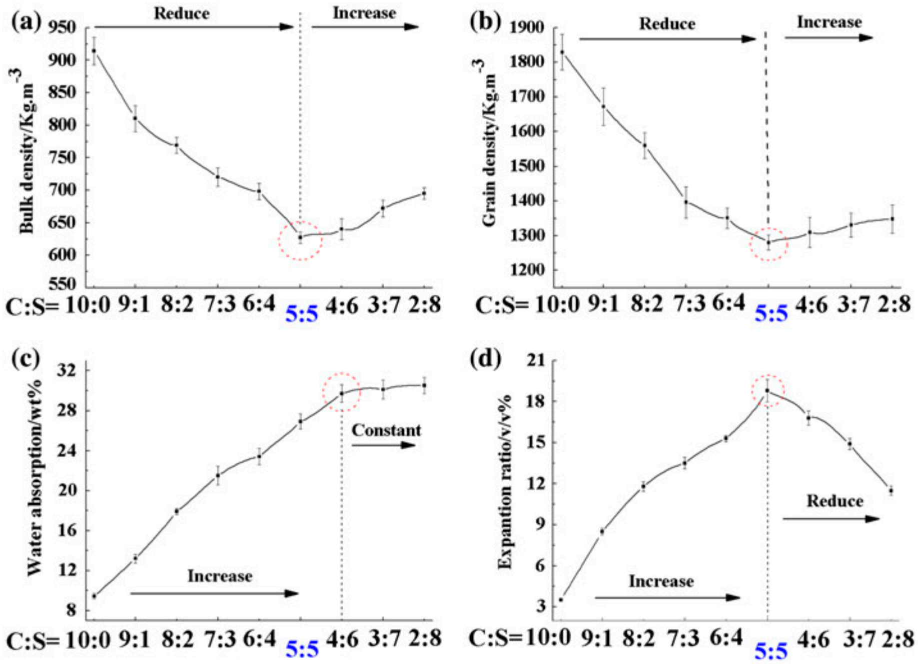

Fig. 4. The properties of LSC prepared from CZ clay and DSD sludge: (a) bulk density; (b) grain density; (c) water absorption; (d) expansion ratio.

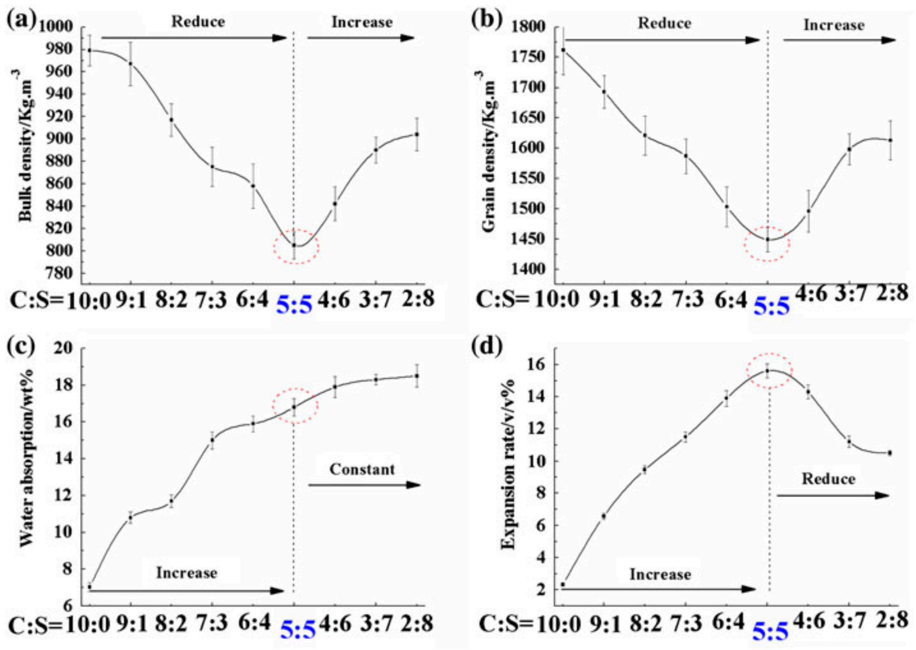

Fig. 5. The properties of LSC prepared from JN clay and DSD sludge: (a) bulk density; (b) grain density; (c) water absorption; (d) expansion ratio.

Table 3
Toxic metal leaching tests of DSD sludge and LSC

Toxic metal	Contents (mg kg^{-1} of DSD sludge)	Contents (mg kg^{-1} of LSC)	National standards (mg kg^{-1} of hazardous waste)
Total Cu	7.82	0.12	≤100.00
Total Zn	4.95	0.15	≤100.00
Total Cd	0.05	0.01	≤1.00
Total Pb	2.46	0.08	≤5.00
Total Cr	0.53	0.17	≤15.00
Total Hg	–	–	≤0.10
Total Ba	1.47	0.09	≤100.00
Total Ni	0.07	0.01	≤5.00
Total As	–	–	≤5.00

standard (GB 5085.3-2007, China) [29]. Although the nine metal contents in lixivium of DSD sludge were lower than the limits of the national standard, the contents of Cu (7.82 mg kg^{-1}), Zn (4.95 mg kg^{-1}), Pb (2.46 mg kg^{-1}), and Ba (1.47 mg kg^{-1}) in lixivium were high, which would be harmful to the environment if it stayed in environment for a long time. Moreover, the contents of the toxic metals (mainly from DSD sludge) in LSC after the heating treatment was much lower than those in the raw DSD sludge before the heat treatment, indicating that the toxic metals in DSD sludge was involved and immobilized in LSC. Thus, DSD sludge utilized as raw materials for sintering LSC could turn hazardous solid waste (DSD sludge) into safe and useful materials (LSC), and the sintered ceramics were nontoxic and would not cause secondary pollution to water environment when applied as fillers.

3.5.2. Microstructure analysis of LSC

Microstructure analysis of commercial ceramics ((a) and (b) surface; (c) and (d) fracture surface) and LSC ((e) and (f) surface; (g) and (h) fracture surface) prepared in the optimum conditions (the mass ratio of CZ clay to DSD sludge was 1:1) is shown in Fig. 6.

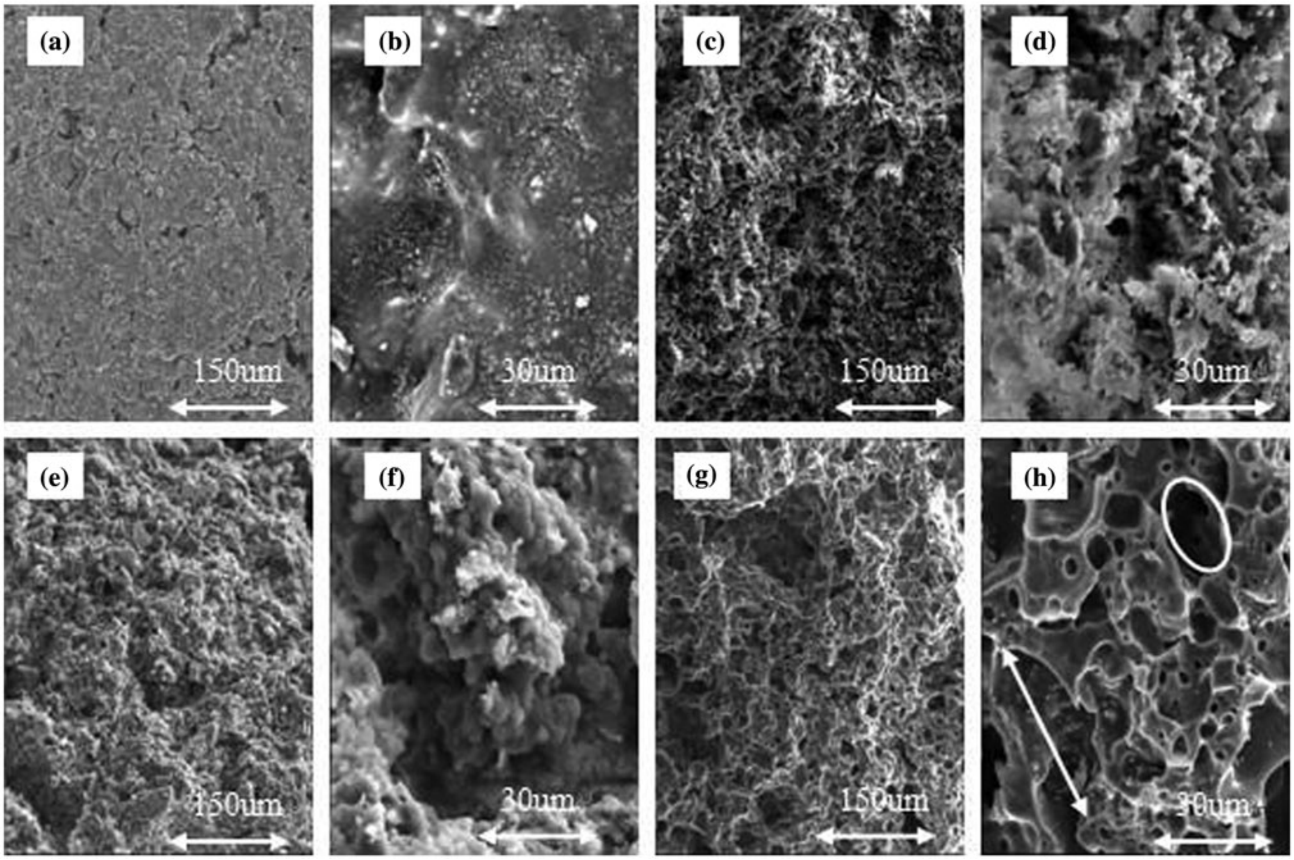

Fig. 6. Microstructure of commercial ceramics and LSC (a) and (b) surface of commercial ceramics; (c) and (d) fracture surface of commercial ceramics; (e) and (f) surface of LSC; (g) and (h) fracture surface of LSC.

Fig. 6(a) and (b) shows that the surface of commercial ceramics is smoother than that of LSC and there are few apertures in the shells of commercial ceramics. Fig. 6(e) and (f) illustrates that LSC had rough surface and there are many small apertures in the shells of LSC. Fig. 6(c) and (d) reveals that the interior of commercial ceramics was dense and apertures inside of commercial ceramics were far smaller than those of LSC. Fig. 6(g) and (h) shows that frames inside of LSC were obviously formed and there were many large apertures in the interior of LSC.

According to above observations, it can be deduced that LSC prepared from CZ clay and DSD sludge was easy for micro-organism to attach when applied as biological media, probably due to the rough surface and porous interior of LSC. Therefore, LSC prepared from CZ clay and DSD sludge might be suitably utilized as fillers in the biological wastewater treatment. LSC applied as fillers in wastewater treatment will be investigated in our subsequent work.

4. Conclusion

Two kinds of clay (CZ clay and JN clay) and DSD sludge utilized as raw materials for preparing LSC were investigated in this research. The conclusions were as follows:

(1) When the two kinds of clay were added, respectively, DSD sludge was utilized as raw material for sintering LSC with the optimum DSD sludge addition rate of approximately 50.0 wt% that was verified to be possible and satisfactory according to the physical properties of LSC.

(2) Through the comparison, CZ clay used as raw materials for preparing LSC was a more suitable choice when DSD sludge was added, and lower bulk (627.00 kg m^{-3}) and grain density (1,280.00 kg m^{-3}) and higher expansion ratio (18.80 v/v%) could be obtained with the optimum DSD sludge addition rate of approximately 50.0 wt%.

(3) LSC prepared from CZ clay and DSD sludge were nontoxic and would not cause secondary pollution to water environment according to toxic metal leaching tests, and the sintered ceramics had rough surface and porous interior according to microstructure analysis, indicating that LSC might be suitably applied as biological media in wastewater treatment.

(4) DSD sludge utilized as raw materials for sintering LSC could be applied to dispose of the hazardous solid waste and turn it into useful materials, which could provide reference for the sludge treatment during DSD acid manufacturing wastewater treatment.

Acknowledgment

This research was supported by Technology Foresight Program of Shandong Province (No. 2012GG E27011).

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