Journal of Cleaner Production 115 (2016) 238–244

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Recycling of polished tile waste as a main raw material in porcelain tiles

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ARTICLE INFO

Article history:
Received 4 January 2015
Received in revised form
17 December 2015
Accepted 17 December 2015
Available online 29 December 2015

Keywords:
Polishing waste
Ceramic tile
Microstructure
Waste utilization

ABSTRACT

The manufacture of traditional porcelain tiles is often associated with a large amount of ceramic wastes during the polishing stage. These wastes need to be properly handled due to the corresponding environment problems. This paper aims to evaluate the possibility of reusing the polished tile waste as a main raw material to produce porcelain tiles. The prepared specimens with various amounts (10–70 wt.%) of the polished tile waste were fired at 1100–1180 °C. The sintering behaviors of fired specimens were examined by linear shrinkage, water absorption and bulk density. The flexural strength of fired specimens was measured by the three-point bending method. The test results show that the sample with 50 wt.% polished tile waste fired at 1120 °C has the superior performance (i.e., water absorption of 0.12%, bulk density of 2.49 g/cm^3 and flexural strength of 47 MPa), which meets the requirement of porcelain tiles according to the ISO 13006 standard. Thus, the polished tile waste can be effectively reused in porcelain tiles as a main and low-cost raw material by fast firing at low temperature. The X-ray diffraction result indicates that introduction of the polished tile waste into porcelain tiles facilitates the formation of mullite phase. In addition, the relationship between the microstructure and strength of the optimal sample was also discussed.

1. Introduction

Porcelain tiles are building materials with outstanding features such as high mechanical strength, wear and chemical resistance (Sanchez et al., 2010; Gabaldón-Estevan et al., 2014). The production of porcelain tiles as one of popular building products grows annually. For instance, in 2014, the porcelain tile production has achieved about ten billion square meters in China. The porcelain tile is usually surface-polished to improve its aesthetic aspect and increase the competitiveness with natural stone materials (Dondi et al., 2005; Sanchez et al., 2006). In the polishing process, the porcelain material in a thickness range of 0.4–0.8 mm from the tile surface is commonly removed, resulting in a large amount of polished tile wastes (PTW). The PTW usually contain approximately 1–5 wt.% of silicon carbide abrasive and 2–6 wt.% of the magnesium oxychloride cement impurities derived from the polishing tool (Alves et al., 2011). It is reported that the output of PTW already exceeds seven million tons per year in China.

Commonly, the PTW is collected and temporarily stored in effluent treatment stations for removing the residual water and producing a mud. Afterwards, it is generally disposed in landfill sites. However, the landfill treatment process could occupy the massive land and waste the mineral resource. There are some previous studies reported on the use of the PTW in concrete (Wattanasiriwech et al., 2009; Elçi, 2015; Jacoby and Pelisser, 2015). In fact, the PTW contain silica (SiO_2), aluminium oxide (Al_2O_3) and flux oxides (i.e., K_2O, Na_2O, CaO and MgO), which are similar to the ceramic material composition. Recycling of the PTW within the same process is a promising approach to manufacture traditional ceramic tiles (Torres et al., 2009; Xi et al., 2014). However, the PTW used in ceramic bodies could be prevented the densification process of ceramics due to the existence of silicon carbide (SiC). The SiC decomposes and forms silica (SiO_2) and carbon dioxide (CO_2) at high firing temperatures (i.e., >1000 °C), giving rise to the related porous microstructure. Therefore, the PTW could be positively recycled only when it was incorporated in low density porous ceramic products (Qi et al., 2010; Ji et al., 2015). However, the requited amount for the porous ceramics in the actual application is smaller (Novais et al., 2015). In addition, Rambaldi et al. (2007) investigated the recycling of the PTW to produce porcelain tiles

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http://dx.doi.org/10.1016/j.jclepro.2015.12.064
0959-6526/

via the replacement of sodium feldspar sand. The content of sodium feldspar sand is not high in the ceramic formula. Thus, the utilization rate of the PTW is relatively low, i.e., about 10 wt. %. This paper was to assess the possibility of the PTW as a main raw material in the production of porcelain tiles. The prepared specimens with various amounts (10–70 wt.%) of the polished tile waste were fired at 1100–1180 °C. The sintering behaviors like linear shrinkage, water absorption, bulk density and flexural strength were evaluated. In addition, the mechanical properties and the microstructure of the final products were also investigated.

2. Materials and methods

2.1. Raw materials

A typical industrial porcelain tile formulation and a dry polished tile waste (PTW) from Foshan Oceano Ceramics Co., Ltd., China were used as raw materials. The porcelain tile (PT) powder used consisted of 35 wt.% clay, 24 wt.% quartz sand, 38 wt.% stone powder and 3 wt.% talcum. The studied body mixes were formulated *via* replacing various amounts of the PT (i.e., 10, 20, 30, 40, 50, 60 and 70 wt.%) based on the same percentages of the dried PTW, respectively.

2.2. Sample preparation

The different mixes were prepared by milling the raw materials with 35 wt.% of water and 0.5 wt.% of polyethylene glycol (Guangzhou Taiqi Chemical Technology Co., Ltd., China) in a porcelain jar mill for 30 min. The raw material powders were subsequently prepared by drying, granulating, and sieving with a 30 mesh sieve. The green bodies in the forms of disks and bars were prepared by dry-pressing the raw material powders at 15 MPa. The sample was sintered in a laboratory electric furnace in air at 1100–1180 °C for 10 min at a heating rate of 20 °C/min.

2.3. Material characterization

The particle size distributions of samples were analyzed by a model BT-9300S laser diffraction particle size analyzer (Dangdong Bettersize Instruments Ltd., China). The sintering behaviors such as linear shrinkage, water absorption and bulk density were determined by the Archimedes method recommended for ceramic tiles, reported in the standard ASTM C373-88 (Christogerou et al., 2009). The crystalline phases of the samples were determined by a model PW-1710 X-ray diffractometer (Philips Co. Ltd., the Netherlands) using Cu *K*a radiation. The thermal analysis was carried out by a model STA449C simultaneous thermogravimetry and differential scanning calorimetry (Netzsch Instruments Ltd., Germany) in air at a heating rate of 10 °C/min. The microstructure morphology of the sintered simples, which were polished or etched by using a 5% HF solution for 2 min, was observed by a model L30FEG scanning electron microscope (Philips Co. Ltd., the Netherlands). The flexural strength of fired specimens was measured at a loading rate of 0.5 mm/min by a model 5569 three-point bending test instrument (Instron Ltd., USA).

3. Results and discussion

3.1. Characterization of PT and PTW

Fig. 1 shows the XRD patterns of the used PT and PTW powder. Clearly, quartz (SiO_2) is the major phase with a small amount of albite ($NaAlSiO_8$), illite ($KMg_3AlSi_3H_2O_{12}$) and kaolinite ($Al_2Si_2H_4O_9$) in the PT. The PTW contains quartz, mullite

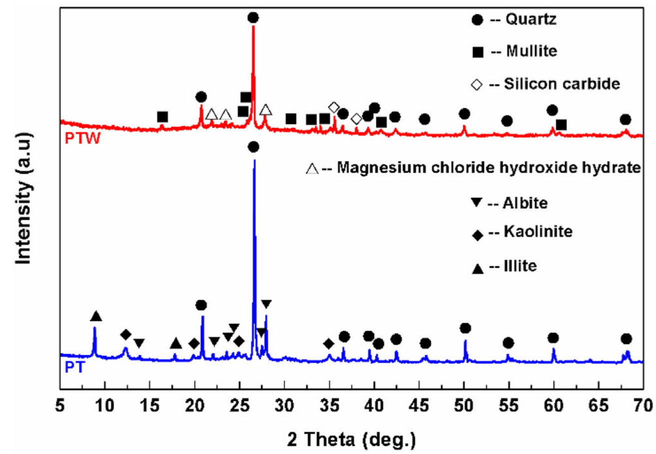

Fig. 1. XRD patterns of the used PT and PTW powder.

($Al_6Si_2O_{13}$), silicon carbide (SiC) and magnesium chloride hydroxide hydrate ($Mg(OH)_2 \cdot MgCl_2 \cdot 8H_2O$) crystalline phases. The first two are from the polished porcelain tiles, and the others are derived from the polishing tool. In addition, the mean particle size of the PTW is smaller than that of the PT (see Fig. 2). The particle size range of silicon carbide (SiC) powders in the PTW sample is 5–10 μm (see Fig. 3).

Table 1 shows the chemical composition of the used PT and PTW powder. The PT and PTW samples are constituted mainly of SiO_2 and Al_2O_3 at the approximate contents. Small difference between the contents of alkaline and alkaline earth oxides (i.e., K_2O, Na_2O, CaO and MgO) exists. Compared to the PT, the PTW sample has a higher content of alkaline earth oxide and a lower content of alkaline oxide, which belong to the low-temperature flux compositions in the porcelain body.

Fig. 4 shows the weight loss and heat flow curves of the PT and PTW powder measured by TG-DTA at a heating rate of 10 °C/min TG-DSC curves of the PT and PTW sample. In Fig. 4a, the TG curve of the PT sample displays a relatively continuous weight loss. The overall weight loss is around 3%. The DSC curve shows an endothermal peak at 448.8 °C, corresponding to the dehydroxylation process of kaolinite. The small endothermic peak at 575.5 °C is attributed to the polymorphic transformation of α-β quartz (Ke

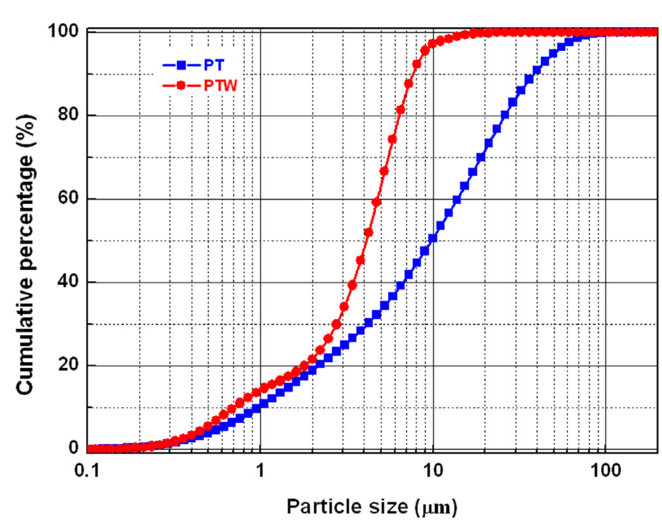

Fig. 2. Particle size distribution of the used PT and PTW powder.