Powder Technology 295 (2016) 133–141

Contents lists available at ScienceDirect

Powder Technology

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

Effect of grinding time on the particle characteristics of glass powder

Shuhua Liu [a,b,*], Qiaoling Li [a], Guoshuai Xie [a,c], Lihua Li [b], Henglin Xiao [b]

[a] State Key Laboratory of Water Resources and Hydropower Engineering Science, Wuhan University, Wuhan, 430072, PR China
[b] School of Civil Engineering and Architecture, Hubei University of Technology, Wuhan 430068, PR China
[c] PowerChina Huadong Engineering Corporation, Hangzhou 310014, PR China

ARTICLE INFO

Article history:
Received 20 November 2015
Received in revised form 17 March 2016
Accepted 19 March 2016
Available online 24 March 2016

Keywords:
Glass powder
Particle characteristics
Distribution model
Fractal theory
Gray correlational analysis

ABSTRACT

Based on laser particle size analysis and activity index test results, the effect of grinding time on particle characteristics of glass powder is systematically investigated with the aid of the Divas–Aliavden grinding kinetic equation, RRB (Rosin–Rammler–Bennet) and Swrebec distribution model, fractal theory and gray correlational analysis in this paper. The results show that the grinding efficiency of glass powder with large particle size tends to decrease with the increase of grinding time, and draws near to zero after 120 min. Both the equivalent particle size and specific surface area (SSA) of glass powder show a good linear relation to logarithm or double logarithm of grinding time. Both RRB and Swrebec function model can adequately describe the particle size distribution (PSD) of glass powder ground for different times, and according to the RRB distribution model, both the characteristic particle size and the distribution index of glass powder show a downward trend with grinding time, which indicates that the grinding process cannot only levigate glass powder, but also widen its PSD. The PSD of glass powder shows obvious fractal features, and its fractal dimension also has an increasing tendency with grinding time. In addition, the activity index of glass powder increases with grinding time. Depending on the gray correlational analysis, the mass fraction of particles ranging 0–3 μm has a maximum positive effect on its activity index at early age while particles ranging 3–10 μm contribute most at later stage. As a result, 90 min is chosen as the optimal grinding time for glass powder in consideration of economical and technical benefits.

1. Introduction

With the development of industrialization and urbanization, a huge quantity of waste glass emerges. Data from the United Nations shows that waste glass has occupied 7% of global solid waste [1]. In developed countries such as Europe and America, the quantity of waste glass made up 4%–8% of the total municipal refuse and America itself produced approximately 12.8 billion tons of waste glass in the year of 2005, of which only 21% has been recycled and the rest are roughly addressed by landfill [2]. Moreover, glass is not bio-degradable. Thus, in the process of landfill, not only are the resources tremendously squandered, but also the environment is badly polluted.

Glass powder, being amorphous and containing relatively large quantities of silicon and calcium, could theoretically be pozzolanic and even be cementitious when it is finely ground [3]. In addition, some researchers have pointed out that glass powder with certain fineness is beneficial to the control of Alkali-silica reaction (ASR) when used as supplementary cementitious materials in concrete [4]. Therefore, the reasonable utilization of glass powder in concrete not only offers a potential for waste glasses recycling but also improves the concrete properties.

However, the finer the glass powder, the longer time it takes to grind, which will definitely increase energy consumption and cost. Furthermore, if glass powder with relatively high fineness continues to be ground, particle agglomeration or "secondary particle" may occur, which may on the contrary decrease its SSA and might weaken its performance in concrete. Besides the particle size characteristics such as fineness and equivalent particle size, grinding time also has a great effect on PSD features as well as activity index of powder materials, which would highly influence the effectiveness and efficiency of the utilization of glass powder in concrete [4–5]. Therefore, it is important to seek out the optimal grinding time for glass powder from economical and technical perspective.

It is assumed that the sieve residue of ground materials with a certain size is R. Apparently, the value of sieve residue R of ground glass powder will gradually reduce with the increase of grinding time. Divas and Fanrenwald have put forward that the reduction rate of sieve residue with a certain particle size ($-dR/dt$) is proportional to the sieve

* Corresponding author at: State Key Laboratory of Water Resources and Hydropower Engineering Science, Wuhan University, Wuhan, 430072, PR China.
E-mail address: shliu@whu.edu.cn (S. Liu).

http://dx.doi.org/10.1016/j.powtec.2016.03.030
0032-5910/

Table 1
Chemical composition of glass powder/mass, %.

SiO_2	CaO	Al_2O_3	Fe_2O_3	Na_2O	K_2O	MgO	Cr_2O_3	MnO	TiO_2
69.17	10.52	2.94	1.47	12.13	1.26	1.16	0.22	0.03	0.06

residue value (R) at one moment during the grinding process [6]. The equation is as follows,

$$\frac{dR}{dt} = -K_t R \tag{1}$$

Where, K_t is the grinding rate constant.

Eq. (1) has been revised by Aliavden, and the kinetic equation used to describe the grinding process of materials is obtained as the following equation,

$$R = R_0 e^{-K_t t^M} \tag{2}$$

Where, R_0 is the initial sieve residue of ground materials with certain particle size; M is the time index and determined by the property of ground material and its grinding conditions. The kinetic equation can be finalized once the two parameters K_t and M are determined [7].

Many researchers have investigated the grinding kinetic equation, especially the effect of grinding process on the grinding parameter K_t [8–10]. Results show that K_t is closely related to the grinding efficiency of ground materials with certain size apart from its property and grinding conditions, and it decreases along with the decrease of grinding efficiency [11–12]. In addition, a great deal of work on the effect of grinding time on the particle characteristics of other powder materials including fly ash, slag, steel slag, etc., have also been done. However, such issues mentioned above have never been systematically discussed on glass powder before.

In this paper, the PSD of glass powder ground for different times are measured by laser particle size analyzer, based on which the parameters of grinding kinetic equations are determined and the effect of grinding time on the particle characteristics is investigated.

2. Experimental

In order to obtain glass powder, the waste beer bottles are collected, cleaned, sun-cured, smashed, and ground for different times, i.e., 10 (A), 30 (B), 60 (C), 90 (D) and 120 (E) min respectively, in a small insulative ball mill of SM 500 × 500 mm, produced by Daoxu machinery factory in Shangyu. The ball mill has a speed of 48 r/min, with the loading capacity of 5 kg sample. The beer bottles

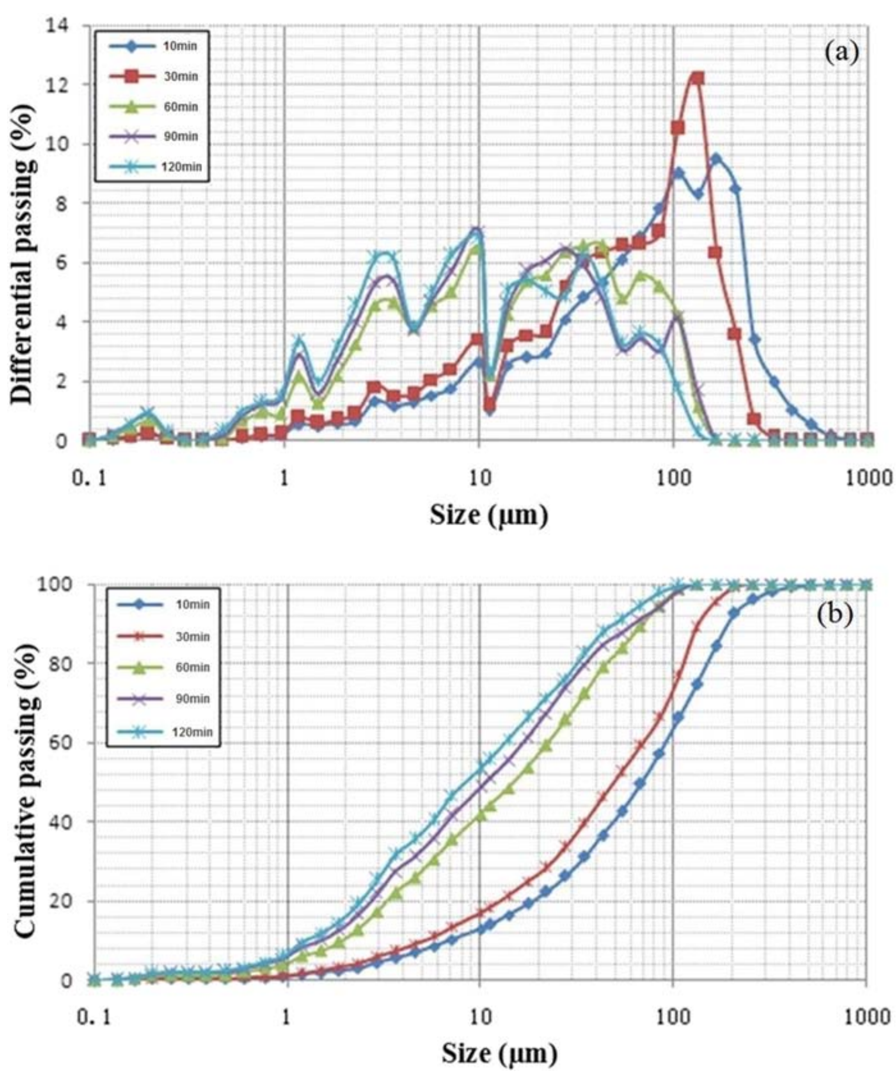

Fig. 1. Particle size distribution curves of glass powder: (a) differential curve, (b) integral curve.