CHEMICAL ENGINEERING TRANSACTIONS Volume 17, 2009
Editor Sauro Pierucci

DOI: 10.3303/CET0917132

Comminution kinetics of steel slag: Influence of microwave pretreatment

Gordana Matijašić, Krunoslav Žižek
University of Zagreb, Faculty of Chemical Engineering and Technology
Marulićev trg 19, 10000 Zagreb, Croatia

Appliance of microwave treatment as a preceding step in the comminution processes has been recognized in many scientific and industrial communities. This work presents the effect of such technique on the comminution efficiency of steel slag, in term of process kinetics.

Steel slag samples, defined as diverse monosized fractions, have been used in this study. Microwave treatment was conducted in a domestic, multi-mode microwave unit at a constant power input. Dry grinding experiments were performed in a laboratory, planetary ball mill. Dynamic aspect of the process was observed at a constant process conditions: operational speed, pot volume, number of balls, etc. Process kinetics was expressed via selection function parameter.

Microwave treatment significantly influences steel slag comminution kinetics.

Divergence in determined selection function parameters depends on the initial sample size. This investigation indicates possible implementation of microwave treatment in steel slag processing for further application.

1. Introduction

Comminution is recognized as highly energy-demanding process. The finer product size is, more input energy is required. Enhancement of energy efficiency could be achieved in different ways. According to Wang and Forssberg (2007) there are several development trends leading to more efficient comminution:

- development and application of new mills/classifiers
- adjustment of bead characterization in stirred bead mills
- hybrid comminution systems with roller-press and media mills
- assisted methods of comminution (grinding aids, microwave-assisted comminution, ultrasound-assisted comminution)
- simulation

The application of thermal energy in assisting material breakage dates from centuries BC when Egyptians used it for liberation of gold from other minerals. Novel methods are based on the same theory but using more efficient heating – microwave heating.

In his review work, Haque (1999) pointed some major advantages of microwave heating over conventional heating: non-contact heating, energy transfer (not heat transfer), rapid and selective heating, volumetric heating, greater control and higher level of safety.

Please cite this article as: Matijasic G. and Zizek K., (2009), Comminution kinetics of steel slag: influence of microwave pretreatment, Chemical Engineering Transactions, 17, 789-794 DOI: 10.3303/CET0917132

Such advantages lead to minimization of input energy, reduction of equipment size and overall cost savings in comminution (Kingman and Rowson, 1998; Jones et al., 2002).
Interest for research of microwave-assisted comminution mostly originates from mineral processing industry. Considerable effort was done in strength reduction of ores and liberation of valuable minerals using microwave energy as shown by Jones et al. (2002), Patnaik and Rao (2004), Kingman et al. (2004), Kingman et al. (2004a), Wang and Forssberg (2005), Jones et al. (2007), Scott et al. (2008). Interesting application of microwave energy is also found in environmental engineering. Jones et al. (2002) presented the role of microwave treatment in soil remediation and waste processing.
Steel slag is a by-product of steel making, produced during the separation of the molten steel from impurities in steel-making furnaces. The chemical composition of steel slag may differ depending on raw materials, but usually contains oxides. Because of unique physical and chemical properties, steel slag is highly suitable substance, mostly in road construction, asphaltic concrete aggregate, portland cement manufacture and various concrete products. Prior to its use as a construction material or cement additive, steel slag must be crushed and screened to specified size required for the particular application.
Yan et al. (2005) reported some changes in microstructure of Chinese slag submitted to microwaves. They also pointed out the benefits of internal and selective heating – shortening the process time and targeting the specified phase that heats effectively. This results indicate the potential application of microwave pretreatment of steel slag in enhancement of comminution efficiency.
Within this work comminution kinetics of steel slag was investigated. Comminution efficiency of steel slag with and without microwave treatment was expressed in terms of selection functions (specific breakage rates). Estimation of those values was made according to well-known size-mass balance equation for batch grinding:

$$\frac{dw_i}{dt} = \sum_{j=1}^{i-1} S_j \cdot b_{i,j} \cdot w_j\left(t\right) - S_i \cdot w_i\left(t\right) \tag{1}$$

where w is mass fraction of material in size interval i or j, S is selection function corresponding to specified size interval and $b_{i,j}$ is mass fraction of material broken from size interval j to size interval i.

2. Experimental methods

2.1 Material

Slag was provided from CMC, Sisak, Croatia. The obtained slag was previously water cooled. Before further processing, slag was left to dry at room temperature for several days. Original slag was received in size smaller than 4 mm. Monosized fractions were obtained using ASTM sieves (-850+600 μm, -1180+850 μm, -1700+1180 μm).
Chemical composition of steel slag is shown in Table 1.

Table 1 Chemical composition of steel slag

	CaO	SiO_2	Al_2O_3	MgO	MnO	Fe_2O_3	bal.
mass %	33.22	10.86	1.66	13.09	6.18	29.64	5.35

2.2 Mill

Comminution kinetics was investigated using planetary ball mill, Fritsch Pulverisette 6. Experimental conditions are shown in Table 2.

Table 2 Experimental conditions

Pot and ball material	agate
Pot volume	10 mL
Revolution speed (operational)	400 rpm
Pot diameter	2.5 cm
Disc diameter	13.5 cm
Ball diameter	12 mm
Number of balls	2
Rotation/revolution ratio	0.82

2.3 Microwave oven

Microwave heating of slag samples was performed in a domestic multi-mode microwave oven operating at 2.45 GHz and 1000 W input power. Prepared size fractions were portioned in smaller quantities and 5 g of sample was placed in a small glass pot, put into the center of MW cavity and heated for 10 min at maximal input power. After cooling at room temperature, sample was heated again for 20 min at the same input power. Microwave pretreated samples were then comminuted using experimental set shown in Table 2.

3. Results and discussion

Selection function can be calculated according to eq. (1) using one-size interval method. For the top size fraction eq. (1) can be written as:

$$\frac{dw_1}{dt} = -S_1 \cdot w_1(t) \tag{2}$$

or

$$\ln w_1(t) = -S_1 \cdot t \tag{3}$$

Equation (3) applies to first-order grinding kinetics.

Fig. 1, 2 and 3 show the change of unbroken material content with comminution time for all tested size intervals with and without microwave treatment. Linear dependence would suggest linear kinetic model. Nevertheless, results showed non-linear change and so-called abnormal breakage. Austin and Bhatia (1971/72) reported that abnormal breakage occurs when the particles are too large in relation to the ball and mill diameter. Such breakage behavior they described with the sum of two first-order breakages.

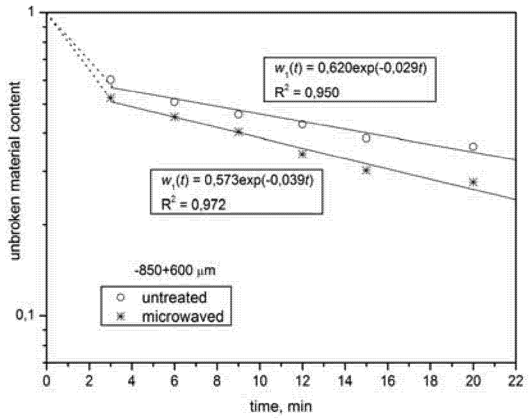

Fig. 1. Feed disappearance in comminution process, size interval -850+600 μm

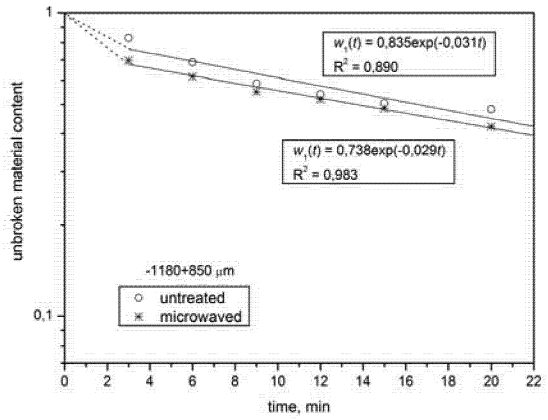

Fig. 2. Feed disappearance in comminution process, size interval -1180+850 μm

Objective of this work was to investigate the influence of microwave treatment on particle breakage behavior. Therefore, selection function determination is only a first approximation in considering mentioned effect. Selection function was evaluated according to linear kinetic model for comminution time greater than 3 minutes. However, further analysis of comminution kinetics would require more detailed modeling and evaluation of selection function according to some non-linear kinetic models.

Results showed that the selection function parameter varies with initial particle size. Selection function of smaller untreated particles showed higher probability of breakage. The same trend was observed for microwave treated samples.

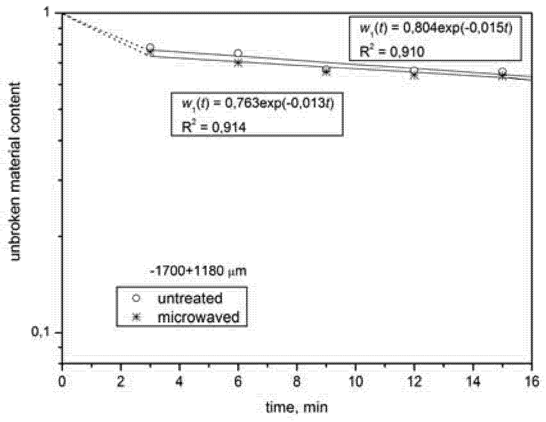

Fig. 3. Feed disappearance in comminution process, size interval -1700+1180 μm

Selection function deviations imply on the effect of microwave pretreatment on the steel slag grindability. Major impact is recorded for the smallest size interval (-850+600 μm) where breakage rate increases from 0.029 min^{-1} to 0.039 min^{-1}. Explanation for microwave influence was found in selective heating of steel slag. Compounds, noted as good absorbers of microwave energy, Fe_2O_3 and MgO, constitute the majority of steel slag mass. They heat rapidly and very intensively. Consequently, distinctive microwave energy susceptibility in steel slag would lead to attenuation of constitutive binds. Similar results were reported in work of Patnaik and Rao (2004) and Haque (1999). Intensity of microwave treatment is less perceived as initial particle size increase. Although, it cannot be neglected that particle size is probably too large in relation to pot diameter in those cases.

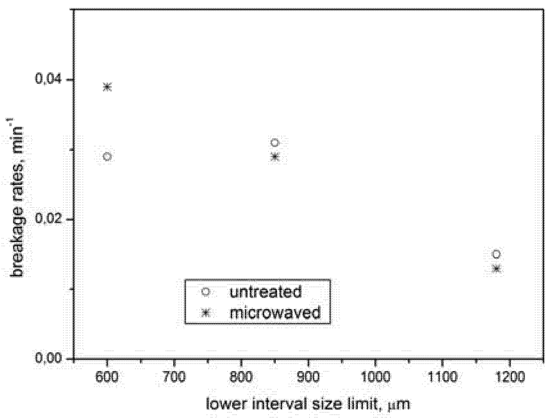

Fig. 4. Breakage rates for different feed sizes of treated and untreated samples.

Fig. 4 summarizes obtained results. Microwave energy can reduce strength of steel slag of smaller initial sizes. Further research, which will include larger pot volumes, larger ball diameters and wider range of particle sizes, is necessary. However, according to presented results, it can be concluded that there is a potential use of microwave energy as a pretreatment method that improves steel slag comminution efficiency.

4. Conclusions

Comminution tests of steel slag samples were provided. Influence of microwave treatment on comminution kinetics was investigated.
Comminution kinetics of steel slag was described as a sum of two first-order kinetics.
Alterations in selection function values imply on the effect of microwave pretreatment on the steel slag grindability and necessity for further research in this area.

References

Austin L.G., Bhatia V.K., 1971/72, Experimental methods for grinding studies in laboratory mills, Powder Technol. 5, 261-266

Haque K. E., 1999, Microwave energy for mineral treatment processes – a brief review, Int. J. Miner. Process. 57, 1-24.

Jones D.A., Kingman S.W., Whittles D.N., Lowndes I.S., 2007, The influence of microwave energy delivery method on strength reduction in ore samples, Chem. Eng. Process. 46, 291-299

Jones D.A., Lelyveld T.P., Mavrofidis S.D., Kingman S.W., Miles N.J., 2002, Microwave heating applications in environmental engineering – a review, Resource, Conservation and Recycling 34, 75-90.

Kingman S. W., Jackson K., Bradshaw S.M., Rowson N.A., Greenwood R., 2004, An investigation into the influence of microwave treatment on mineral ore comminution, Powder Technol. 146, 176-184.

Kingman S. W., Jackson K., Cumbane A., Bradshaw S.M., Rowson N.A., Greenwood R., 2004a, Recent developments in microwave-assisted comminution, Int. J. Min. Process. 74, 71-83.

Kingman S. W., Rowson N. A., 1998, Microwave treatment of minerals – a review, Min. Eng. 11, 1081-1087.

Patnaik N., Rao R.B., 2004, Microwave energy in mineral processing – a review, Mining Eng. 84, 56-61.

Scott G., Bradshaw S.M., Eksteen J.J., 2008, The effect of microwave pretreatment on the liberation of a copper carbonatite ore after milling, Int. J. Miner. Process. 85, 121-128.

Wang Y., Forssberg E., 2005, Dry comminution and liberation with microwave assistance, Scand. J. Metall. 34, 57-63.

Wang Y., Forssberg E., 2007, Enhancement of energy efficiency for mechanical production of fine and ultra-fine particles in comminution, China Partic. 5, vol. 5, 193-201.

Yan C., Yoshikawa N., Taniguchi S., 2005, Microwave heating behavior of blast furnace slag bearing high titanium, ISIJ Int. 45, vol 9, 1232-1237.