A STUDY ON THE SPECIFIC RATE OF BREAKAGE OF DIFFERENT LIMESTONES FROM LAO PDR AND MALAYSIA IN A LABORATORY BALL MILL

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Abstract

Effects of the different limestones and feed size on the specific rate of breakage (S_i) were investigated at batch grinding conditions based on kinetic model. Six different mono-size fractions were prepared between 212 and 20 µm. The specific rates of breakage were determined from the size distributions at different grinding times, and the specific rates of breakage were compared for four limestone samples taken from different geological origin (Baling limestone-L_B, Vangvieng limestone-L_V, Laungprabang limestone-L_L and Oudomxay limestone-L_O). The results indicated that the different properties of limestone had a significant effect to the specific rate of breakage. The L_B limestone gave the fastest rates of breakage because of its prominent cleavages texture, whereas the L_O limestone had the slowest rates of breakage which this is due to its high content of impurities such as silica, magnesia, alumina and iron oxide. The variation of the specific rate of breakage with feed size of limestones studied show that the feed size of -75+53µm gave the highest rate of breakage compared to other feed sizes for L_V, L_L and L_O samples; while the size fraction of -106+75µm was the best feed size for L_B sample.

Keywords: Ball mill, Breakage rate, Feed size, Grinding, Limestone

Introduction

Comminution is extremely energy intensive, consuming 3-4% of the electricity generated worldwide and comprising up to 70% of all energy required in typical mineral processing plant. Considering these factors, a small gain in comminution efficiency can have a large impact in the operating cost of a plant, while conserving resources as well [1, 2].

Grinding has been utilized in manufacturing fine and ultra-fine powders for the development of new materials and for improving product quality. For a long time, grinding processes, especially on ball mills, have been subjected to statistical and kinetic analysis [3].

In the recent years, the matrix model and kinetic model, which are suggested by investigators, have been used in laboratories and industrial areas. The kinetic model, which is an alternative approach, considers comminution as a continuous process in which the rate of the breakage of particle size is proportional to the mass present in that size [1].

The analysis of size reduction in tumbling ball mills using the concepts of specific rate of breakage has received considerable attention in years [4, 5]. Austin et al. [6] have reviewed the advantages of this approach and the scale-up of laboratory data to full-scale mills has also been discussed in a number of papers.

When breakage is occurring in an efficient manner, the breakage of a given size fraction of material usually follows a first-order law [1, 4, 7]. Thus, breakage rate of material, which is in the top size interval, can be expressed as:

$$\frac{-dw_1}{dt} = S_1 w_1(t) \quad \cdots\cdots \quad (1)$$

Assuming that S_1 does not change with time (that is, a first-order breakage process), this equation integrates to:

$$\log(w_1(t)) - \log(w_1(0)) = \frac{-S_1 t}{2.3} \quad \cdots\cdots \quad (2)$$

where $w_1(t)$ and $w_1(0)$ are the weight fraction of the mill hold-up that is of size 1 at time t and 0, respectively [1, 4, 5, 6, 8]. S_1 is the specific rate of breakage and is determined from the slope of $w_1(t)/w_1(0)$ versus t on a semi-log plot. This rule is known as the first order grinding hypothesis. For the variation of the specific rate of breakage, Si with particle size is:

$$S_i = a_T X_i^{\alpha} \quad \cdots\cdots \quad (3)$$

where: X_i is the upper limits of the size interval indexed by i (mm), and a_T and α are the model parameters that depend on the properties of the material and the grinding conditions.

This paper presents the effects of characteristic and feed size of the different limestone samples on the specific rate of breakage determined under constant conditions in a small laboratory ball mill.

Materials and Methods

Samples from naturally occurring limestone deposits were sought from three different resources in Lao PDR and one resource in Malaysia. These natural limestones belong to different geological formation that manifested by diverse and unique mineralogical, chemical, textural properties (grain size, particles, etc.) and physical properties. These different and unique limestone resources are further designated as:

- Limestone from Baling deposit, Kedah, Malaysia (L_B)
- Limestone from Vangvieng deposit, Vientiane, Laos (L_V)
- Limestone from Laungprabang deposit, Laungprabang, Laos (L_L)
- Limestone from Oudomxay deposit, Oudomxay, Laos (L_O)

Samples were subjected to mineralogical and chemical analyses using X-ray diffraction (XRD) and X-ray fluorescence (XRF) techniques (Table 1). The physical and mechanical properties of the raw material were indicated in Table 2. Thin sections of these limestones were prepared for microscope examination under transmitted light (Olympus BX41 Polarizing microscope).

Table 1. Chemical Composition of Limestone Samples

Chemical Composition	L_B (wt. %)	L_V (wt. %)	L_L (wt. %)	L_O (wt. %)
MgO	0.389	0.557	0.394	6.719
Al_2O_3	0.310	0.074	0.224	4.716
SiO_2	1.005	0.079	1.537	10.640
P_2O_5	0.006	0.009	0.030	0.046
SO_3	0.019	0.029	0.018	0.574
K_2O	0.059	0.004	0.021	0.918
CaO	54.644	55.205	54.441	37.630
MnO	0.006	-	0.013	0.044
Fe_2O_3	0.146	0.016	0.065	1.547
SrO	0.017	0.045	0.029	0.012
LOI	43.36	43.98	43.21	36.91
Mineralogical Composition				
Calcite	Major	Major	Major	Major
Quartz	Minor	Trace	Minor	Minor
Dolomite	Trace	Trace	Trace	Minor

Table 2. Physical and Mechanical Properties of Limestones Samples

Limestone Resources	Gs	ϕ (%)	Wa (%)	UCS (MPa)
L_B	2.7	0.71	0.27	65.15
L_V	2.76	0.35	0.13	72.36
L_L	2.69	0.66	0.24	59.16
L_O	2.72	2.19	0.81	62.97

Gs = bulk specific gravity, ϕ = porosity, Wa = water absorption and UCS = uniaxial compressive strength

The experiments were performed in a laboratory mill with a 1595 cm^3 volume whose characteristics and test conditions are described in Table 3. Six mono-size fractions (-212+180, -180+106, -106+75, -75+53, -53+38 and -38+20 μm) were prepared and ground batch-wise (grinding time: 1, 2, 4, and 8 minutes) in a laboratory-scale ball mill for determination of the breakage functions and in order to study efficiency of grinding performance for different limestone resources. Each sample was taken out of the mill and poured onto the Riffle Sample Divider to obtain the identical sub-samples and dry-sieved for product size analysis.

Table 3. Experimental Conditions of a Laboratory Ball Mill

Milling Chamber:	
- Material	Ceramic
- Diameter, D_m (mm)	125
- Length, L (mm)	130
- Volume, V_m (cm^3)	1595
Mill Speed:	
- Critical, N_c (rpm)[a]	122
- Operational (75% of N_c), (rpm)	90
Media Charge:	
- Material	Ceramic
- Diameter, d_b (mm)	5
- Specific gravity (g/cm^3)	3.6
- Assumed porosity, φ (%)	40
- Ball-filling volume fraction, J_B (%)[b]	20
Material Charge:	
- Material	Limestone
- Specific gravity (g/cm^3)	2.70 (L_B); 2.76 (L_V); 2.70 (L_L); 2.72 (L_O)
- Powder-filling volume fraction, J_R (%)[c]	4
- Powder-ball loading, U (%)[d]	50

[a] *Calculated from* $N_C = 42.3 / \sqrt{D_m - d_b}$ *(D_m, d_b in meter) [9]*

[b] *Calculated from* J_B *= (mass of balls/ball density) / (V_m (1-φ)) [10]*

[c] *Calculated from* J_R *= (mass of powder/formal bulk density) / (V_m (1-φ))*

[d] *[10] Calculated from* $U = J_R / (J_B \varphi)$ *[5, 10]*

Results and Discussion

Microphotographs of limestones recorded using transmitted light microscopy are illustrated in Figure 1. As shown, Figure 1 (A) reveals that the grain sizes of Baling limestone (L_B) are generally exhibited as fine to large size grains (~2.5 mm) which are distributed inhomogenously throughout the rock mass and also showing the prominent cleavage outlines. For L_V resource, in hand specimen this rock is so finely crystalline that individual crystals cannot be resolved and it appears to be homogenous micrite. Thin section reveals that allochem (ooids) is present among micrite crystals (Figure 1 (B)). Thus, this rock can be categorized as Oomicrite limestone when based on Folk classification (1962). Whereas, for L_L samples, the skeleton grains (especially foraminiferan grains) are presented in micrite matrix (Figure 1 (C)). This type of rocks can be classified as Biomicrite limestone according to Folk's classification (1962). For L_O resource, thin section under plane polarized light reveals that the quartz grains (white color) and dolomite are presented among micrite crystals (Figure 1 (D)).

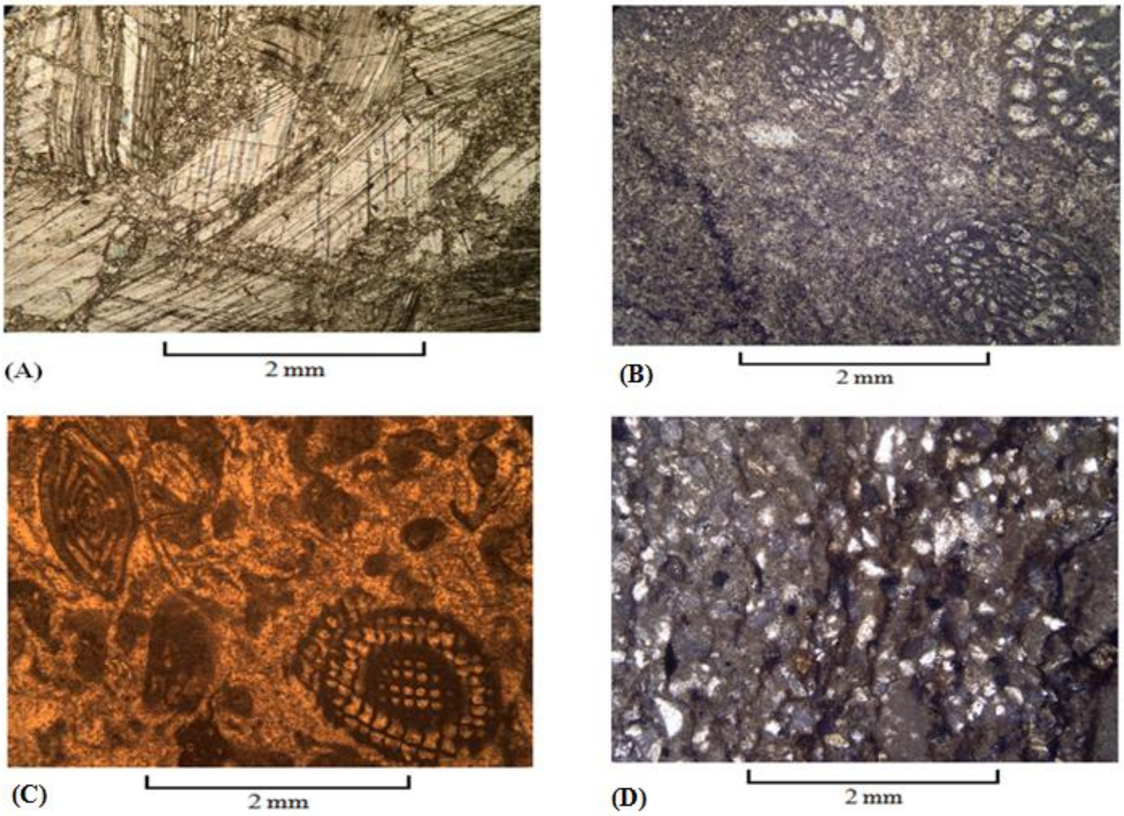

Figure 1: Photomicrographs of limestones thin section: (A) L_B, (B) L_V, (C) L_L and (D) L_O

Detailed chemical analysis results of the four limestone resources are shown in Table 1. Generally, the identification of CaO, Fe_2O_3, MgO, Al_2O_3 and SiO_2 is important to characterize the quality of the limestone chemical composition. The theoretical composition of calcium carbonate is 56 wt% CaO and 44 wt% CO_2.The CaO of the L_B, L_V and L_L resources ranges from 54.44 wt% to 55.20 wt% which can classify these limestone resources as high to very high purity limestones. While, the L_O resource has the CaO content less than 37.63 wt% which can be considered as impure limestone (magnesia limestone).

Table 2 shows the results for bulk density, porosity and water absorption of limestone samples. The results indicate that mean values of bulk density for all four limestone resources ranges from 2.70 g/cm^3 to 2.76 g/cm^3. The highest bulk density value is found in L_V resource (2.76 g/cm^3), which having the lowest porosity (0.35%) and water absorption values (0.13%) among the four limestone resources. This might be due to its very fine grains size which distribute homogenously through the mass rock (very dense rock). The porosity and water absorption values for Oudomxay limestone (L_O) show the big difference in comparison with the rest of the samples. This might be due to the high content of magnesia. Water absorption results show the variations (0.11-1.10%). The highest results might refer to the effect of the solution on the matrix.

The first-order plots for the various feed sizes of limestone samples are illustrated in Figures 2-5. The results indicated that breakage generally follows the first-order relation. In addition, parameters of specific rate of breakage to supply by first-order plots are present in Table 4. The specific rates of breakage of each size fraction that exhibited first-order grinding kinetic behavior were determined from slope of straight-line of first-order plots.

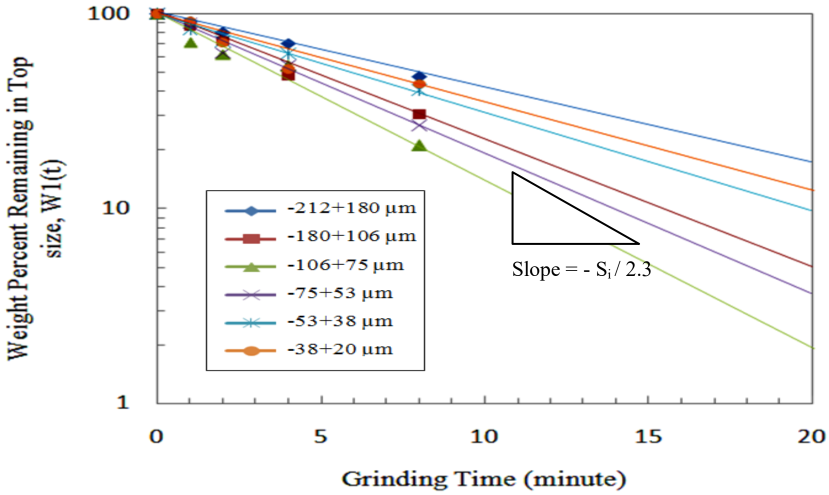

Figure 2. First-order plots for L_B

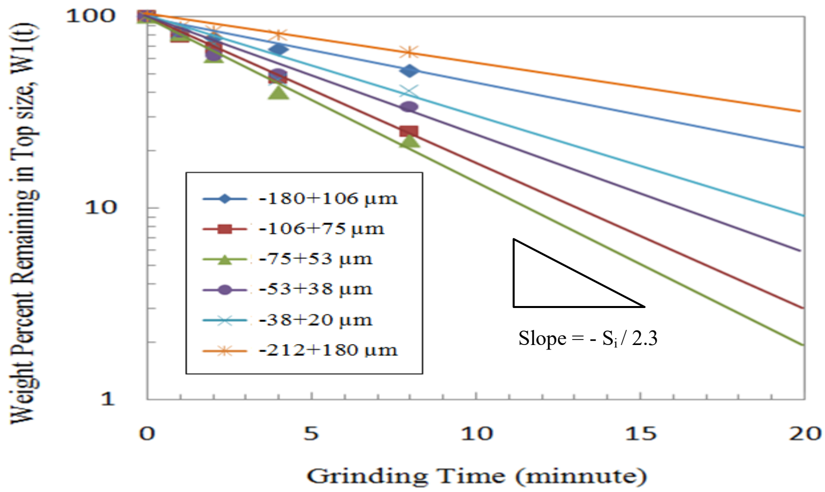

Figure 3. First-order plots for L_V

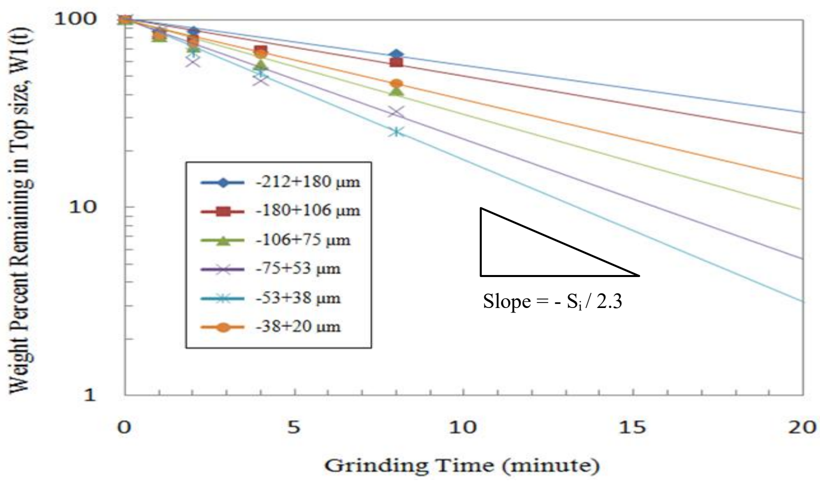

Figure 4. First-order plots for L_L

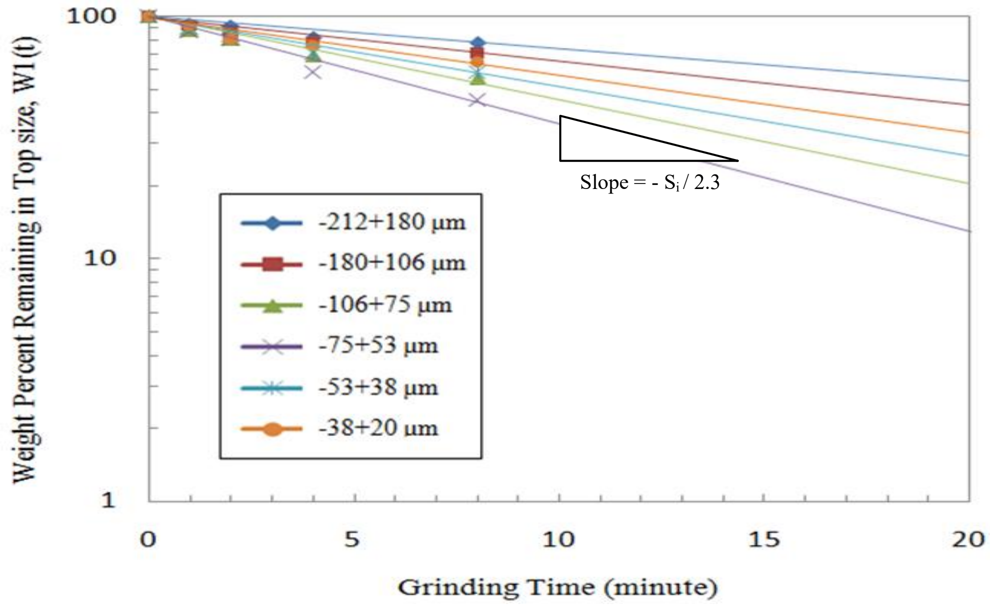

Figure 5. First-order plots for L_O

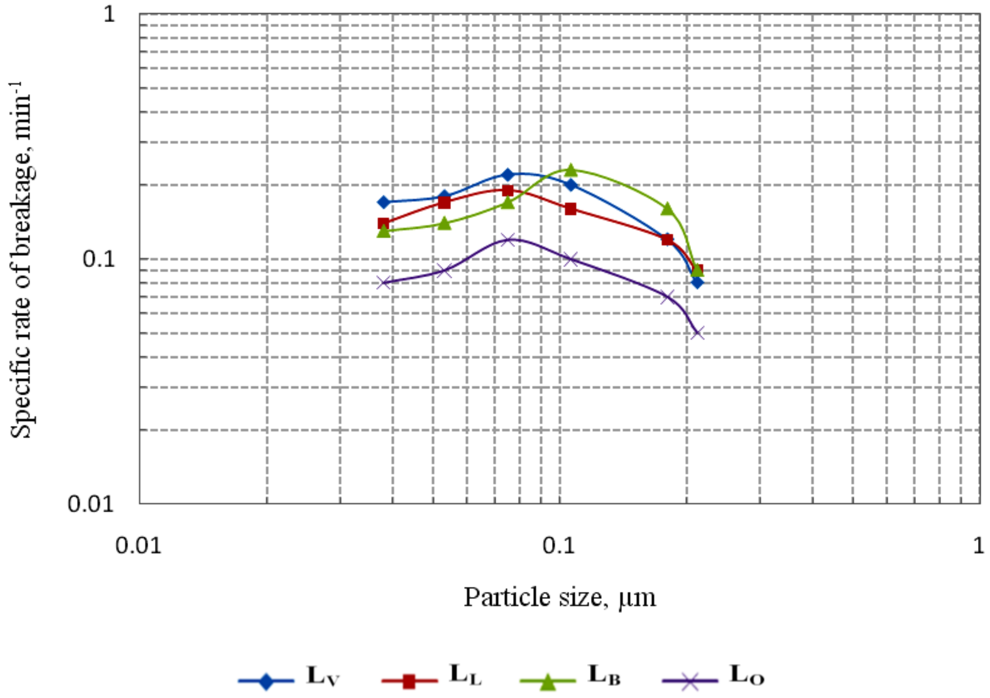

Figure 6. Variation of specific rates of breakage with particle size for different limestone resources

Figure 6 shows the values of S_i for grinding of the four different limestone samples, as a function of size. The results show that specific rate of breakage increase up to -75+53 µm feed size, but above this size fraction breakage rates decrease slightly for L_V, L_L and L_O samples, since the particles are too large and hard to be properly nipped and fractured by the selected ball size, and have a slow specific rate of breakage. Whereas, the specific rate of breakage of L_B samples increase up to -106+75µm feed size and start decreasing above this size fraction.

Table 4. Characteristic Breakage Parameters for Limestone Samples

Limestone Resources	Feed Size (µm)	S_i (min^{-1})	a_T	α
L_B	F1 (-212+180)	0.09	0.761	0.557
	F2 (-180+106)	0.16		
	F3 (-106+75)	0.23		
	F4 (-75+53)	0.17		
	F5 (-53+38)	0.14		
	F6 (-38+20)	0.13		
L_V	F1 (-212+180)	0.08	0.576	0.38
	F2 (-180+106)	0.12		
	F3 (-106+75)	0.2		
	F4 (-75+53)	0.22		
	F5 (-53+38)	0.18		
	F6 (-38+20)	0.17		
L_L	F1 (-212+180)	0.09	0.615	0.448
	F2 (-180+106)	0.12		
	F3 (-106+75)	0.16		
	F4 (-75+53)	0.19		
	F5 (-53+38)	0.17		
	F6 (-38+20)	0.14		
L_O	F1 (-212+180)	0.05	0.55	0.598
	F2 (-180+106)	0.07		
	F3 (-106+75)	0.1		
	F4 (-75+53)	0.12		
	F5 (-53+38)	0.09		
	F6 (-38+20)	0.08		

Si = Specific rate of breakage, a_T and α = Model parameters that depend on the properties of the material and the grinding conditions

In ball mill, grinding can be done by several mechanisms, including impact/compression, due to forces applied almost normally to the particles surface; chipping due to oblique forces; and abrasion due to forces acting parallel to the surface. These mechanisms distort the particles and change their shape beyond certain limits determined by their degree of elasticity, which causes them to break. The degree of elasticity is depended on properties of the particles which will give the different in comminution rate.

As can be seen from Figure 6, the different properties of limestone had a significant effect to the specific rate of breakage. The L_B limestone gave the fastest rates of breakage among the four limestone samples; this is because of its prominent cleavages texture. As L_B samples have large crystals which contain many flaws and defects on mineral grains or on grain boundaries (cleavage). During grinding process, the grinding mechanisms distorted the L_B limestone particles and broke easily along its prominent cleavages. Whereas, L_V, L_L and L_O had lower comminution rates due to its strong interlocking matrix and micro-crystalline structures. As the grinding mechanisms distorted along these strong interlocking matrix thus made them difficult to break. The L_O limestone, however, had the slowest rates of breakage which this is due to its high content of impurities such as silica, magnesia, alumina and iron oxide. These impurities are hard minerals which made L_O samples were harder to break.

The variation of the specific rate of breakage with feed size of limestones studied show that the feed size of -75+53µm gave the highest rate of breakage compared to other feed sizes for L_V, L_L and L_O samples; while the size fraction of -106+75µm was the best feed size for L_B sample.

Conclusions

This study has investigated the effects of the different limestones and feed size on the specific rate of breakage (S_i) based on kinetic model. The following conclusions can be drawn based on the experimental results:

- The different properties of limestone had a significant effect to the specific rate of breakage.
- The L_B limestone gave the fastest rates of breakage because of its prominent cleavages texture, whereas the L_O limestone had the slowest rates of breakage which this is due to its high content of impurities such as silica, magnesia, alumina and iron oxide.
- The variation of the specific rate of breakage with feed size of limestones studied show that the feed size of -75+53µm gave the highest rate of breakage compared to other feed sizes for L_V, L_L and L_O samples; while the size fraction of -106+75µm was the best feed size for L_B sample.
- The comminution rate constant related strictly to the properties of minerals to be ground.

Acknowledgments

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