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COMMUNICATIONS

GRINDABILITY OF MIXTURES OF CEMENT CLINKER AND TRASS

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ABSTRACT

The Bond method of grindability was applied to clinker and trass and to their mixtures. Kinetic experiments also were carried out in the Bond ball mill with each component and the mixtures to obtain a better understanding of the interactions taking place in mixture grinding. The Bond work indices of mixtures were not simply weighted averages of the component work indices, and they were higher than the work index of the harder component clinker. The breakage rate and breakage distribution parameters of the dominant and harder phase clinker were both time and mixture-composition independent for short grinding times, whereas those parameters of the minor and softer phase trass were time independent but mixture-composition dependent. © *1998 Elsevier Science Ltd*

Introduction

The last step in the process of manufacturing composite cements is the finish grinding of clinker and a small amount of gypsum (3–4%) together with at least two other components to produce multicomponent cement powder to meet specific surface area and strength requirements. The additional components, generally interground with the clinker, are normally pozzolanic materials, such as trass (compact volcanic tuff) and fly ash, or an inert filler, such as limestone. The production of composite cements is of interest both from economical and ecological points of view (1–3).

It is common knowledge that energy consumption in cement clinker grinding circuits is a significant portion of the total electrical energy used. The effectiveness with which the energy invested in the grinding process is utilized depends on, besides many other material- and machine-dependent factors, the particulate environment in which the material is ground. The interaction between different kinds of particles in the mill affects the grindability of the constituent particulate solids. The grindability of a material is favourably or unfavourably altered to a great extent in a heterogeneous environment (4), which is of particular interest in the context of energy saving in the manufacture of composite cements. It appears from the pertinent literature that the grindability of composite cements is better than the individual

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grindability of the clinker in the composite (3), and that intergrinding of cement raw materials, limestone and clay, is less energy demanding than their separate grinding, especially at high levels of fineness (5).

The most widely known measure of grindability is Bond's work index of grindability (6). The Bond grindability is empirically related to the energy requirement at the pinion shaft of industrial tumbling mills and, thus, is useful for mill sizing on the basis of predicted mill power to give a desired capacity in normal closed-circuit grinding operations. There is little information in the literature concerning the estimation of the Bond grindability of composite cements or mineral mixtures. Yan and Eaton (7) investigated the variation of the Bond work index of ore blends as a function of blend composition and found that the work index of a mixture was not simply the weighted mean of the work indices of the components, and that the harder ore had the greatest influence on the value of the index.

The kinetic approach to the size reduction provides a better understanding of the grinding mechanisms and interactions taking place in the mill than the Bond method of grindability. The description of grinding of a given particle size class as a rate process contains two parts: the breakage rate function (k_i value), which gives the fractional rate at which material is broken from the size class at time t; and the breakage distribution function (b_{ij} values), which gives the fraction of material that becomes particles in the i-th size class when material in the j-th size class is broken. A cumulative breakage distribution function B_{ij} is commonly used to accumulate b_{ij} values, which defines the cumulative mass fraction of material that becomes particles finer than the upper size limit of the i-th size class when material in the j-th size class is broken (8). These parameters occupy a central position in the analysis of single mineral and mixture grinding.

In the present work we studied the grindabilities of cement clinker and trass and their binary mixtures with the Bond method. The objective was to compare the grindabilities and analyze the breakage properties (breakage rate and breakage distribution functions) of the individual components and their admixtures in two different volume ratios.

Experimental

The as-received samples of cement clinker and trass were first dried at ambient temperatures in the laboratory, and then stage crushed to −6 mesh with jaw and roll crushers to prepare crude feed stock of each material. The crude feeds were split into representative smaller batches, which were oven dried at 105°C. The air-pycnometer densities of clinker and trass were 3.10 and 2.70 g/cm^3, respectively.

The Bond grindability tests were performed with the −6 mesh dry feed materials in a standard ball mill (30.5 × 30.5 cm) following a standard procedural outline described in the literature (9). The packed bulk densities of the Bond test feeds for clinker and trass were 1.44 and 1.64 g/cm^3, respectively. Work indices were determined at a test size of 200 mesh (74 μm). First, clinker and trass were separately tested in the Bond mill, and then tests were carried out with two clinker–trass admixtures containing 20% and 35% by volume (17% and 31% by weight) trass, so as to comply with composite cement compositions. Feed and product size distributions were determined by dry sieving. In the case of mixtures, the undersize products from the last cycle of the Bond tests were chemically analyzed for their trass contents.

The kinetic experiments also were conducted in the Bond mill with 700-cm^3 (packed

TABLE 1
Bond grindability test results.

Sample	Work index (k Wh/ston)		Product surface area (cm^2g^{-1})	% of trass in product
	Experimental	Calculated		
Clinker (C)	13.49		1700	
Trass (T)	11.65		3520	
80% C + 20% T	14.79	13.12	2125	20.7
65% C + 35% T	14.31	12.85	2600	35.5

volume) monosized samples of 14 × 20 mesh in size, obtained by the screening of the −6 mesh material on a vibratory screen. Monosized clinker and trass samples, either individually or in mixtures, were ground dry in the mill for 0.5, 1.0, 2.0, and 4.0 min. The ground product from each test was first dry sieved to determine the overall size distribution. In the case of mixture grinding, each size fraction was analyzed for trass to obtain the size distribution of the components. The breakage rate functions and breakage distribution functions of the components for the feed size (14 × 20 mesh) were determined by the methods developed on the basis of the first-order disappearance and the zero-order production relationships, respectively (10).

Results and Discussion

Bond Ball Mill Grindability Tests

Results of the Bond tests are given in Table 1. Experimental work indices for singly ground clinker and trass are the mean of two replicates. The replicate values are 13.08 and 13.89 for clinker, and 11.52 and 11.78 for trass. Calculated W_i values for the mixtures are the weighted averages of the work indices of the individual components on volume–fraction basis. The work index of clinker is greater than that of trass, indicating that clinker requires more energy than trass to grind both materials 80% passing 200 mesh.

A comparison of the experimental and calculated W_i values for the mixtures of various proportions indicates that the experimental W_is are greater than the volume–fraction basis calculated W_i values by a margin in excess of the measured experimental variation of the Bond tests. The experimental W_i values for the mixtures are greater than the W_i value for clinker individually ground. That is, in contrast to previous opinions on the grindability of composite cements (3), the grindability of the clinker–trass mixture is worse than the individual grindability of the clinker, the predominating component in the mixture. It is likely that the presence of relatively soft trass particles shields harder clinker particles from being ground, leading to an unfavorable effect on the mixture grindability. Furthermore, trass contents of the Bond test last cycle products given in the last column of Table 1 indicate that, at steady state, the percentage of trass in the test product is close to its original percentage in the test feed. This finding is in agreement with industrial grinding practice of composite

TABLE 2
Particle size distribution (in percent) of the bond test products (−200 mesh).

	Sample			
Sieve size (μm)	Clinker (C)	Trass (T)	80% C + 20% T	65% C + 35% T
74 × 45	24.8	20.2	18.2	15.8
45 × 25	59.2	51.8	68.4	64.2
−25	16.0	28.0	13.4	20.0

cements in the sense that the percentages of the metered components in the composite cement product do not change when the grinding plant is in steady-state operation (11).

Cement properties such as water demand, setting behaviour, and strength development are quite sensitive to the Blaine specific surface area as well as the particle size distribution. Table 1 shows that the specific surface area of the trass product is almost twice that of the clinker product for the same top size (200 mesh), and that the addition of trass into the feed proportionately increases the surface area of the ground composite product. The particle size distributions of the Bond test products given in Table 2 show that, when ground alone, trass produces more −25 μm particles than clinker, whereas most of the particles accumulate in the intermediate 25 × 45-μm size fraction in both cases. The trass product has a wider and finer particle size distribution yielding a greater specific surface area. Mixture grinding of the two components increases the proportion of the intermediate size particles in the mixture test product as compared to individual grinding of the components. It is very likely that the presence of trass hinders the grinding of clinker particles down to sizes finer than 25 μm. A similar finding was reported in an earlier study (1), where it was found that pozzolanic additive tuff prevented the enrichment of clinker below 25 μm, which adversely affected 3-day specific cement strength.

Breakage Rate and Distribution Functions

Figure 1 presents plots of the mass fraction of original feed remaining versus grind time and verifies the validity of first-order breakage kinetics for clinker and trass when ground alone or as components of a binary mixture. Data points for clinker in mixture grinding are not shown in the figure for the sake of clarity as they coincide with the data points for clinker ground alone. These linear plots show that, in all cases, the breakage rates are time independent for the short grinding times studied here. The feed size (14 × 20 mesh) first-order breakage rate functions (k_1 values) given in the figure are numerical values of the slope of each line.

The breakage rate of trass, the softer component with lower work index, is considerably higher than that of clinker when both are ground alone or in an admixture. The rate of grinding of the harder component (clinker) is practically the same when ground alone or in mixture; that is, the breakage rate function values for clinker are mixture-composition independent, at least within the grinding time period examined, when clinker is the dominant phase in the mixture. The grinding rate of trass is decelerated to a small degree when it is

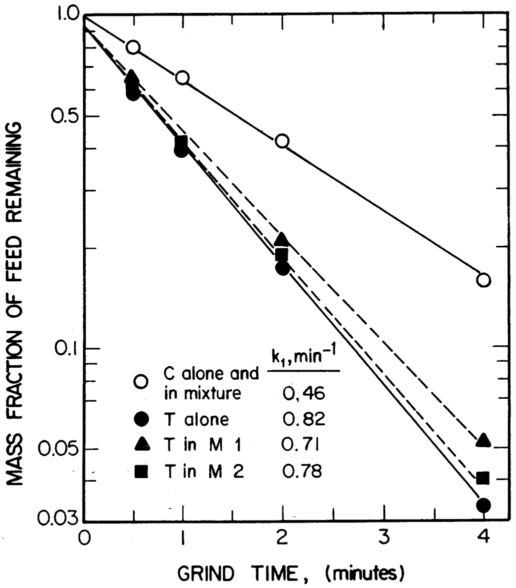

FIG. 1.

First-order feed-size disappearance plots for clinker (C) and trass (T) when ground alone or in mixture (M 1: 80% C + 20% T; M 2: 65% C + 35% T).

present in relatively small amount (20%). A plausible cause for this slowing-down effect is that the probability for trass particle being caught between the grinding media and, hence, being selected for breakage, should decrease when trass is the minor phase in mixture.

Figure 2 presents plots of the cumulative feed-size breakage distribution functions (B_{i1} values) for clinker and trass whether ground alone or as components in an admixture. The B_{i1} values are said to be mixture-composition (or environment) independent if the plots fall on top of one another for a material when it is ground alone or in an admixture. It is obvious from the plots that the B_{i1} values for clinker can be considered environment independent, whereas those for trass are environment dependent. More fines were produced upon breakage of trass particles as the volume fraction of trass in the mixture was decreased. This effect is more evident with sample containing 20% trass and indicates a change in the breakage mechanism from shattering by ball impacts to more chipping and abrasion by harder clinker particles. The aforementioned slowing-down effect in the breakage rate of trass also may be partly attributed to this change of breakage mechanism.

Conclusions

The following conclusions can be drawn from this study:

1. The Bond work index of a clinker–trass admixture is not simply the weighted average of the work indices of clinker and trass, and it is greater than the work index of the harder component clinker.

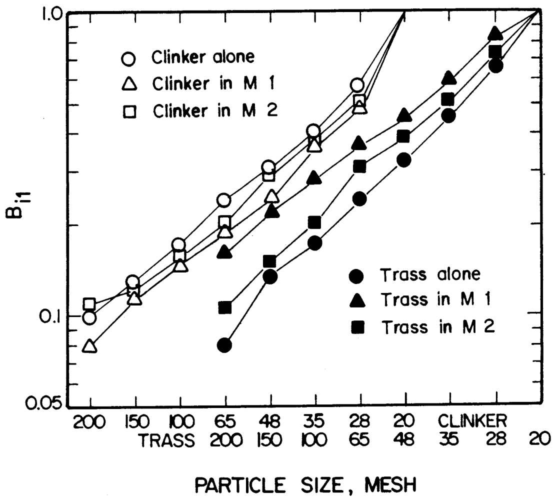

FIG. 2.

Cumulative feed-size breakage distribution functions (B_{i1}) for clinker (C) and trass (T) when ground alone or in mixture (M 1: 80% C + 20% T ; M 2: 65% C + 35% T).

2. The breakage rate function of clinker, the harder and dominant component of the mixtures examined, is both time and mixture-composition independent for short grinding times, but the breakage rate of trass is mixture-composition dependent, especially when it is present in small amounts.
3. The feed-size breakage distribution functions of clinker are practically the same, irrespective of whether it is ground by itself or as a component of mixtures; however, those of trass are mixture-composition dependent.

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