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STUDY OF THE BEHAVIOR OF BINARY MIXTURE GRINDING USING THE FIXED-TIME LOCKED - CYCLE TESTS

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Abstract:

Ores are generally very heterogeneous in their physical properties. Variation of the ore from a mine can cause the mill feed to vary in grindability. In the comminution of heterogeneous materials, an understanding of how different constituents behave by themselves and how they interact with each other may prove useful not only for understanding grinding mill action but also for obtaining the optimum values which used in mathematical modelling. Locked cycle tests show that in the grinding of mixtures relatively long time is required to attain steady state, during which the composition of the mill contents continuously change. Therefore, the main objective of this work is to study the behavior of the components of limestone-quartz binary mixture at different ratios of mixing from the start point to attain the steady state condition using the experimental fixed-time locked-cycle tests. It is shown that attaining the steady state condition in a fixed time locked cycle is faster with low circulating load for soft material than those for hard one when they ground separately. As admixture, the hard component appearance increases gradually with decreasing the fineness of the product as its percentage increases in the feed.

Keywords: Comminution of binary mixtures; psedu closed circuit; fixed time locked; cycle; grinding circuits

1. Introduction

During the past few years, extensive efforts have been directed towards automatic control of grinding circuits to optimize the utilization of comminution energy and the recovery of minerals by minimizing overgrinding [1-3]. Testing the response of an industrial scale grinding system to variations in operating variables can be an expensive undertaking. On the other hand, laboratory-scale experimentation that simulate continuous closed-circuit grinding can provide detailed information which might be extended to predicting the response of full-scale comminution systems under dynamic conditions [4-7]. Locked cycle grinding tests are widely used for assessing the grindability of industrial minerals and ores, for the design and scale up of industrial mills, and for studying the likely behavior of industrial grinding circuits under different operating conditions [8-11].

These tests experimentally simulate on the laboratory scale a tumbling mill operating under plug flow conditions in a closed loop with a classifier which may or may not be perfect. It is well known that locked cycle tests are time consuming, laborious, and prone to experimental errors. Therefore, based on appropriate mathematical algorithms, several accurate simulation schemes have been proposed to economize on the experimental component of these tests [12-16]. In a locked cycle grinding test, a fixed amount of crushed feed solid material is ground in tumbling mill and the comminuted product is screened on a prescribed mesh of grind. The oversize component is combined with new makeup feed and the grinding cycle is repeated. The cycles are continued until in theory at least, the grinding system reaches a steady state-that the weight of the recycle material, the new makeup feed and the undersize product become constant. The locked cycle test at equilibrium is equivalent to the steady state [6]. Considerable advances have been made in the last two decades in evolving kinetic models for the analysis of comminution operations. Through such models in conjunction with mill transport models, mill design, operation and control can now be conceived in a rational and meaningful way [12]. Most of the published work to test these models has been carried out with single minerals or more-or-less homogeneous materials [17-20].

A calcite-quartz mixture was employed as a feed for conducting fixed-time locked cycle grinding tests by Kapur et al [13]. They showed that multicomponent feeds comprising hard and soft minerals in different proportions should provide a more realistic model representation on the dynamic of closed-circuit grinding heterogeneous industrial ore. These complex ores, of course, are of primary importance, both in terms of the tonnage ground and the comminution energy expended. On the other hand, compared to single-component feeds, much more experimental effort is required for locked-cycle grinding of mixture feed, not only is the numbers of cycles needed to attain steady state significantly higher, but also it is necessary to analyze the composition of the recycling mass or the finished product at end of each cycle. Therefore, the objective of the work presented in this paper is to study the behavior of the components of the limestone-quartz binary mixture in a locked cycle at different ratios of mixing from the start point to the steady state condition using the experimental fixed-time locked-cycle tests technique.

2. Experimental Work

Given amounts of limestone and quartz of size -4+2 mm are ground separately and as admixture in a batch ball mill for fixed times . The experimental work was conducted using a ball mill of 14 cm length and 16 cm inside diameter with a volume occupied with the total load (grinding media and ore charge) of 55% of the total mill volume. 90% of the voids between media charge was filled with ore. The grinding media consisted of 54 balls of 2.5 cm diameters, 108 balls of 2 cm diameter and 122 steel balls of 1.5 cm diameter. The mill was operated with 80 rpm which represent 75% of its critical speed. The fixed grinding times were 2 minutes for limestone, and 5 minutes for quartz and admixture of limestone and quartz. The percentage of quartz weight was changed to be 20%, 40%, 60% and 80% of the total admixture weight which filled the interstitial voids between balls. This corresponding to 80%, 60%, 40% and 20% of limestone weight respectively as illustrated in Table. (1). Product of each ground fixed period is sieved on -200 µm screen. The oversize material is returned to the mill with sufficient new feed (-4+2 mm) to maintain the holdup constant. The total material charge is ground again for the subsequent fixed period. This step is repeated until steady state is attained. The weight of each component in the admixture experiments was appointed by dilute HCL dissolution.

Table (1) Weights of separate and admixture of limestone and quartz

separate		**Mixture of limestone and quartz**							
Quartz (gm)	**Limestone (gm)**	**20% Q**		**40% Q**		**60% Q**		**80% Q**	
		Q	L	Q	L	Q	L	Q	L
810	700	162	560	324	420	486	280	648	140

3. Results and Discussions:

Grinding each of limestone and quartz separately illustrated that reaching the steady state for limestone (18 minutes) with a circulating load of 178% is faster than that of quartz (45 minutes) with a circulating load of 188%. The final product (-200 µm) of limestone is finer than that of quartz as shown in Table (2) and Fig. (1) these findings support those obtained by Fuerstenau and Venkataraman [12], and Kapur et al [13]. This behavior may be due to the high difference in their hardness.

Table (2) Particle size analysis of the ground limestone and quartz final products (-200 µm) at the steady state condition when they ground separately

Particle size (µm)	**Mean particle size (µm) (D_i)**	**Limestone**				**Quartz**			
		Wt.% ret.	**Wt. % ret. ×D_i**	**Comm. wt% ret.**	**Comm. wt% passed**	**Wt.% ret.**	**Wt. % ret. ×D_i**	**Comm. wt% ret.**	**Comm. wt% passed**
-200+160	180	14.52	2613.9	14.52	100.00	47.4	853.2	47.4	100.0
-160+125	142.5	11.29	1608.8	25.81	85.48	10.6	1510.5	58.0	52.6
-125+100	112.5	7.10	798.8	32.91	74.19	10.2	1147.5	68.2	42
-100+71	85.5	12.26	1048.2	45.17	67.09	14.4	1231.2	82.6	31.8
-71+63	67	5.81	389.3	50.98	54.83	6.8	455.6	89.4	17.4
-63+0.0	31.5	49.02	1544.1	100.00	49.02	10.6	333.9	100.0	10.6
Median diameter (µm)			80.03				132.11		

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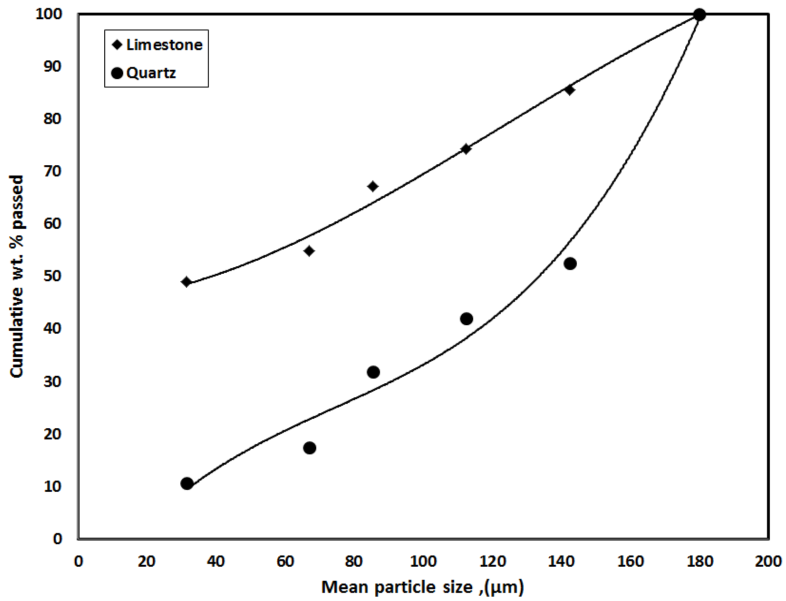

Fig. (1) Particle size distribution of separately ground limestone and quartz final products (-200 µm) at the steady state condition

Results of the admixture study from 20% to 80% quartz are listed in Table (3). This table contains the particle size analysis of the product at the steady state condition for the different studied admixtures. This table includes also the median diameter of each studied mixture as well as the percentage of quartz in the product of each studied mixture. Fig. (2) represents the effect of the percentage of quartz in the feed on its appearance in the product at the steady- state conditions. From this figure it is clear that, the appearance of quartz increases gradually with a constant slope in the product as its percentage increased in the feed. This behavior may be due to that quartz is mono mineral. This interpretation agrees with that proposed by Powell and Morrison [15]. Fig. (3) clears that the median of the ground mixture increases as the percentage of quartz in the feed increases. This behavior may be attributed to the higher strength of quartz as it transfers the energy from balls to limestone particles which increases their grindability. Fig. (4) Represents the particle size distribution of each studied mixture. This figure reflects also that the product becomes coarser as the percentage of quartz increases in the feed.

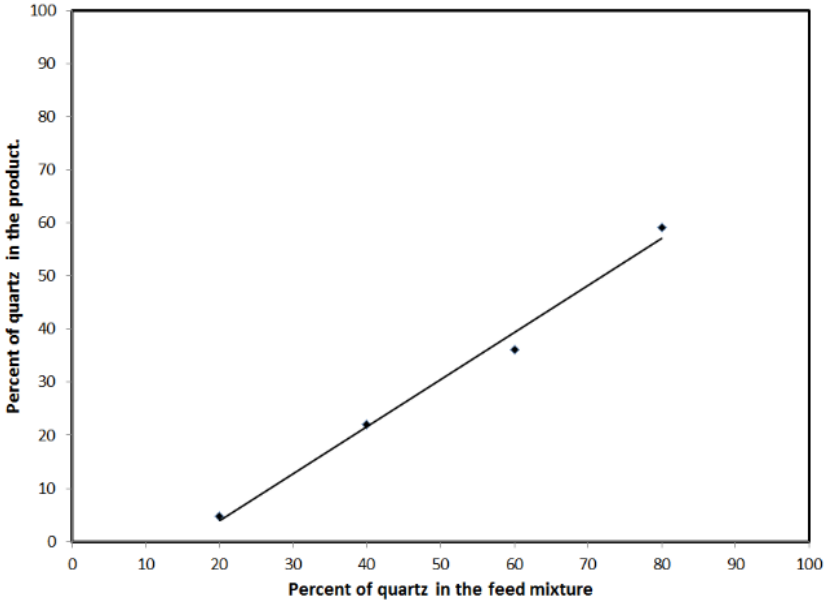

Fig. (2) Effect of the percentage of quartz in the feed mixture on its percentage in the product.

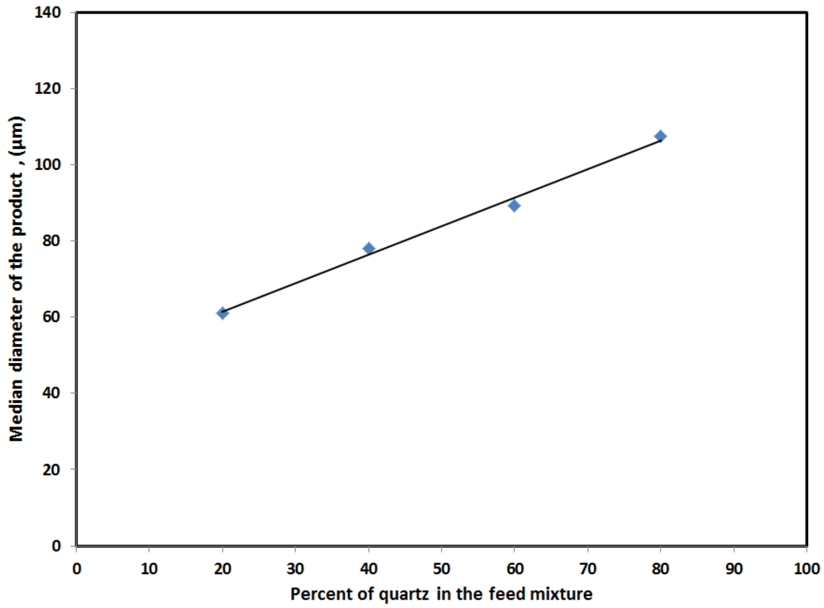

Fig. (3) Effect of the percentage of quartz in the median diameter of the product.

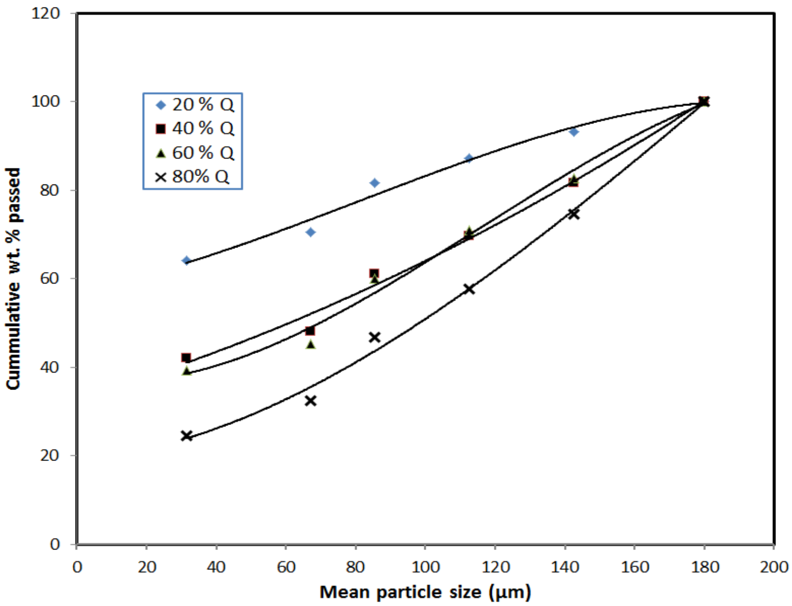

Fig. (4) Particle size distributing of the ground mixture undersize (-200µm) at the steady state conditions.

Particle size (μm)	Mean particle size (μm) D_i	20% Q				40% Q				60% Q				80% Q			
		Wt % ret.	Wt% ret. $\times D_i$	Cum.wt% ret	Cum.wt% pass	Wt % ret.	Wt% ret. $\times D_i$	Cum.wt% ret	Cum.wt% pass	Wt % ret.	Wt% ret. $\times D_i$	Cum.wt% ret	Cum.wt% pass	Wt % ret.	Wt% ret. $\times D_i$	Cum.wt% ret	Cum.wt% pass
-200+160	180	6.92	1245.6	6.92	100.00	18.42	2315.6	18.42	100	17.26	3106.8	17.26	100	25.53	4595.4	25.53	100
-160+125	142.5	5.98	852.2	12.90	93.08	11.84	1687.2	30.26	81.58	11.90	1695.8	29.16	82.74	16.76	2388.3	42.29	74.47
-125+100	112.5	5.45	613.1	18.35	87.10	8.55	961.9	38.81	69.74	10.72	1206.0	39.88	70.84	10.90	1226.3	53.19	57.71
-100+71	85.5	11.17	955.0	29.52	81.65	13.16	1125.2	51.97	61.19	14.88	1272.2	54.76	60.12	14.36	1227.8	67.55	46.81
-71+63	67	6.38	427.5	35.90	70.48	5.92	396.6	57.89	48.03	5.95	398.7	60.71	45.24	7.98	534.7	75.53	32.45
-63+0.00	31.5	64.10	2019.2	100.00	64.10	42.11	1326.5	100.00	42.11	39.29	1237.6	100.00	39.29	24.47	770.8	100.00	24.47
Median diameter (μm)		**61.13**				**78.13**				**89.17**				**107.43**			
Quartz % (in the product)		**4.79**				**22.04**				**36.15**				**59.10**			

6. Conclusions

From this study it can be concluded that:

- Attaining the steady state in a fixed time locked-cycle is faster with low circulating load and final product for soft material (limestone) if compared with those for hard material (quartz) when they ground separately.
- For the admixture, increasing the percentage of the hard component in the feed increases its appearance gradually in the product. This increase is accompanied with decrease in the fineness of product and increase in the time arrival of the steady state.

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"دراسة سلوك طحن خليط ذو مكونين باستخدام اختبارات دائرة الطحن المغلقة ذات الفترات الزمنية الثابتة"

الملخص العربي:

الخامات عامة غير متجانسة في خواصها الطبيعية، ويؤدى اختلاف هذه الخواص إلى اختلاف سلوك طحنها، لذا يتطلب الأمر دراسة سلوك مكونات هذه الصخور وكيفية تصرفها مع بعضها أثناء الطحن ليس فقط من أجل عملها أثناء الطحن ولكن يفيد ذلك أيضا في الوصول إلى القيم المثلى التي تستخدم في عمليات النمذجة الرياضية.

توضح اختبارات الدائرة المغلقة للمخاليط أن هناك وقت طويل تحتاجه للوصول إلى حالة الاتزان التي أثناؤه تختلف هذه المكونات بمرور زمن الطحن. لذا فالهدف الرئيسي من إجراء هذا البحث هو دراسة سلوك خليط من الكوارتز والحجر الجيري عند نسب خلط مختلفة من بداية التشغيل حتى الوصول إلى حالة الاتزان باستخدام اختبارات الطحن في الدائرة المغلقة ذات الفترات الزمنية الثابتة.

وقد أوضحت الدراسة أن زمن الوصول إلى حالة الاتزان يكون أسرع والحمل الدوار يكون أقل ودرجة نعومة المنتج تكون أكبر بالنسبة للخام الأقل صلابة (الحجر الجيري) إذا ما قورنت بمثيلاتها للخام الأكبر صلابة (الكوارتز) عندما تم طحن كلا منهما على حده. وعند دراستهما كخليط بنسب خلط مختلفة تظهر نسبة المكون الأصلب تدريجيا بزيادة نسبته في خام التغذية مع قلة درجة نعومة المنتج النهائي وزيادة زمن الوصول إلى درجة الاتزان.