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Optimization of Grinding Efficiency of a Dolomite Plant to Cater Glass Manufacturing Industry

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Abstract

The glass industry necessitates stringent particle size specifications for raw materials such as dolomite to ensure product integrity and process quality. In this paper, it is suggested that there is a systematic study to optimize the grinding efficiency of a dolomite processing plant to meet such stringent specifications. The research focused on the optimization of a pre-existing secondary ball milling circuit to produce a higher dolomite percentage of particles size lesser than 700 µm, while closely controlling the production of fines (<150 µm). The selection of dolomite with improved grinding characteristics was based on material pre-characterization through Aggregate Impact Value (AIV) and moisture content. Three systematic ball mill studies were conducted to examine various breaking mechanisms in different feed size ranges (5-1.7 mm, 3-1.7 mm, and 1.7 mm-700 µm). The experiments indicate an interdependence between feed size and media charge. The final optimized trial, with a fine feed (1.7 mm-700 µm) and intermediate-weighted ball charge (30% 60 mm, 50% 40 mm, 20% 30 mm), could successfully produce a product that contained 90.2% passing 600 µm while 29.3% passing 150 µm. The outcome confirms the two-stage grinding strategy and offers a fact-based path to success in meeting the glass industry's specifications.

Keywords: Ball charge, Ball mill, Comminution, Feed size, Glass industry, Grinding optimization, Particle size distribution

1 Introduction

Dolomite, $CaMg(CO_3)_2$, is a raw material used in several industrial applications, mostly in the production of glass, ceramics, and fertilizers [1]. Dolomite is used in the production of glass by adding it to the batch melt as a source of magnesium oxide (MgO) and calcium oxide (CaO). These oxides act as fluxing agents, lowering the melting point of the silica-based mix, and as stabilizers, enhancing the chemical durability, workability, and weatherability resistance in the final glass product [2].

The functionality of dolomite in glass manufacturing is greatly dependent on its physical characteristics, particularly its Particle Size Distribution (PSD). Glass manufacturers put high specifications to obtain an even melt and prevent defects. The dolomite feed should typically be fine enough, with an upper size (e.g., 100% passing 700 µm) and a simultaneous restriction on percentage of excessive fines (e.g., less than 20% passing 150 µm). Undissolved oversized particles have the potential to create inclusions, while excessive fines are liable to dust in the furnace, leading to operational issues and an effect upon melt chemistry [2].

Sri Lanka possesses extensive dolomite deposits, which are located predominantly in the Precambrian marble rocks of the Highland Complex [3]. However, their comminution for economic high-value industrial applications is an area requiring extensive technical development. Metal Mix (Pvt) Ltd., a local producer, utilizes an autogenous (AG) milling circuit for primary dolomite grinding. This circuit has been found to be inefficient, with only approximately 25% of the output falling within the required PSD for the glass industry. Previous research at the same site by Gohulan et al. [4] had verified that reducing the feed size for the AG mill would improve its operation, however it was not sufficient to reliably meet target specifications, and hence a standalone secondary grinding stage was required.

To address this capability requirement, the company proposed the addition of a secondary ball mill (900 mm x 1800 mm). Ball mills are common equipment for fine and ultra-fine grinding however their operation is governed by a multidimensional set of operating parameters, i.e., mill speed, media type, media charge, and feed characteristics [5], [6]. The realization of this secondary circuit relies on a scientific optimum and knowledge of these variables.

This research aimed to optimize the feed particle size distribution and grinding media ball charge composition in a new ball mill circuit, aiming to develop a robust strategy for consistently producing glass-grade dolomite as per the specifications:

i. To select the most suitable dolomite feed material based on its intrinsic physical properties relevant to grinding behavior.
ii. To systematically evaluate the effect of different feed particle size ranges on the final product PSD and grinding efficiency.
iii. To investigate the effect of different ball charge compositions on the dominant breakage mechanisms (impact vs attrition) and the resulting product quality.
iv. To identify an optimum set of operating conditions (feed size and ball charge) that maximizes the yield of the required particle size and minimizes the formation of unwanted fines.

This paper presents the overall findings of this applied research in an effort to narrow the gap between fundamental comminution theory and practical industrial needs of Sri Lankan glass manufacturing industry.

2 Methodology

The experimental program was designed to systematically analyse the grinding process by isolating and testing the primary variables of feed size and media composition. All laboratory tests were carried out as per relevant international testing standards.

2.1 Material Characterization and Selection

Two petrographically different types of dolomites ('Planar' and 'Crystal') from the Matale-Naulla deposit were characterized in order to choose the best feed material on the basis of grindability influencing properties.

2.1.1 Aggregate Impact Value (AIV) Test

The AIV test, which is a measure of a stockpile's shock or impact resistance. A weighted sample was placed in a cylindrical steel cup and subjected to 15 standard blows from a 13.5-14.0 kg hammer fallen from a calibrated height of 38 ± 0.5 cm as per IS 2386-5 [7]. The crushed material was then sieved through a 2.36 mm sieve, and the weight of the passing fraction was found. The AIV was calculated using Equation (1) as per IS 2386-5 [7].

$$\text{AIV (\%)} = \frac{W_2}{W_1} \times 100 \qquad (1)$$

Where, W_1=initial weight of the sample and W_2=weight of fraction passing through 2.36 mm sieve.

2.1.2 Moisture Content Test

The moisture content of the dolomite samples was determined by oven-drying representative samples to constant weight or at 110 °C ± 5 °C for 24 hours as per ASTM D2216 [8].

According to the results, Planar Dolomite was chosen for all the other grinding tests because it has higher mechanical strength.

2.2 Ball Mill Grinding Trials

The grinding tests were conducted at Metal Mix (Pvt) Ltd using a pilot-scale, batch-operated industrial ball mill. The mill's specifications were an internal diameter of 900 mm, an internal length of 1800 mm, a 15-kW motor, and a constant speed of 36.3 r/min, or approximately 70–75% of its critical speed.

2.2.1 Feed Preparation

The selected Planar Dolomite was screened into three distinct, narrowly classified feed size fractions for testing:

- Coarse Feed: 5 mm - 1.7 mm
- Intermediate Feed: 3 mm - 1.7 mm
- Fine Feed: 1.7 mm - 700 µm

2.2.2 Grinding Media and Ball Charge

The grinding balls consisted of heavy alumina ceramic balls of nominal diameters 60 mm, 40 mm, and 30 mm. The total ball charge weight was kept constant at 1000 kg. Three different compositions of the ball charge by weight were attempted:

- Trial 1 (Balanced Charge): 40% 60 mm, 30% 40 mm, 30% 30 mm.
- Trial 2 (Coarser Charge): 50% 60 mm, 40% 40 mm, 10% 30 mm.
- Trial 3 (Optimized Charge): 30% 60 mm, 50% 40 mm, 20% 30 mm.

Number of trials was limited to three considering very high operational cost per each trial.

2.2.3 Experimental Procedure

For each test run, a representative sample of a chosen dolomite size fraction was dry ground for a standard duration. When the grinding period elapsed, the mill was stopped, and the entire product was carefully discharged, homogenized by standard coning and quartering methods, and sampled for particle size analysis.

2.3 Sieve Analysis

The PSD of the ground product of every trial was determined by dry sieve analysis using a series of calibrated woven wire mesh sieves. The series of sieves had apertures of 1.700 mm, 1.180 mm, 0.600 mm, 0.425 mm, 0.300 mm, 0.150 mm, and 0.075 mm. With the aid of a mechanical sieve shaker, the particles were separated efficiently for 10 minutes per sample.

3 Results

3.1 Material Characterization

The physical property tests confirmed a notable difference between the two dolomite variants. The results are summarized in Table 1.

Table 1: Comparison of Physical Properties

Property	Planar Dolomite	Crystal Dolomite
Average AIV (%)	20.89	21.75
Moisture (%)	0.156	0.08

The Planar Dolomite contained much less AIV, demonstrating that it is more mechanically sound and resistant to fracturing under impact. It was therefore selected as the feedstock for all grinding tests to provide better control over the generation of fines.

3.2 Grinding Trial Results

The results of the three test trials showed a strong relationship between the composition of the ball charge and the feed size. PSDs for each trial are presented in Tables 2, 3, and 4.

Table 2: Product Passing (%) for Trial 1 (Balanced Charge: 40/30/30)

Sieve Size (mm)	Feed (mm): 5 - 1.7	Feed (mm): 3 - 1.7	Feed (mm): 1.7 - 0.7
1.700	99.1	99.1	99.0
1.180	95.5	97.9	95.1
0.600	81.5	88.0	81.6
0.425	67.9	76.5	71.6
0.300	56.5	63.4	43.5
0.150	32.9	37.9	29.4
0.075	13.4	19.2	11.2

Table 3: Product Passing (%) for Trial 2 (Coarser Charge: 50/40/10)

Sieve Size (mm)	Feed (mm): 5 - 1.7	Feed (mm): 3 - 1.7	Feed (mm): 1.7 - 0.7
1.700	99.7	99.6	98.4
1.180	99.6	98.7	94.6
0.600	97.8	91.5	73.4
0.425	92.6	85.3	61.3
0.300	87.0	77.2	51.1
0.150	71.8	58.2	30.3
0.075	19.2	18.2	11.9

The final trial focused on intermediate and fine feed ranges, as the coarse feed range (5 mm to 1.7 mm) generated excessive fines beyond industry specifications (<20%). These three systematic trials were designed to establish key relationships between feed size and media charge composition, providing directional guidance for process optimization.

Table 4: Product Passing (%) for Trial 3 (Optimized Charge: 30/50/20)

Sieve Size (mm)	Feed (mm): 3 - 1.7	Feed (mm): 1.7 - 0.7
1.700	99.4	100.0
1.180	98.3	99.6
0.600	89.5	90.2
0.425	76.4	75.6
0.300	60.2	51.1
0.150	37.9	29.3
0.075	7.0	4.4

3.3 Analysis of Optimized Performance

The primary goal of this study was to determine the grinding conditions that produce the highest percentage of product passing the 600 µm sieve while also minimizing the formation of fines below 150 µm. The results of the experiments indicate a clear and logical progression toward this optimum across the three trials.

Figure 1 provides a direct visual representation of how the three different ball charges performed when grinding the most significant feed size for this secondary grinding analysis: the fine feed (1.7 mm - 700 µm). This feed is considered the most critical because it represents the material that requires precise, controlled size reduction rather than coarse, primary breakage. The success of the entire two-stage process hinges on the ability to efficiently grind this specific fraction to the final specification without creating excessive fines. The performance of each trial was different:

- Trial 2 was the least successful due to inefficient use of large media for grinding fine particles.
- Trial 1 showed significant improvement, with 81.6% passing through 600 µm and generating 29.4% of fines.
- Trial 3 was the superior condition, producing the best product at 90.2% passing 600 µm and maintaining 29.3% of fines generation. This indicates that the intermediate-weighted charge of Trial 3 achieved more effective size reduction without additional over-grinding penalty, resulting in a more efficient application.

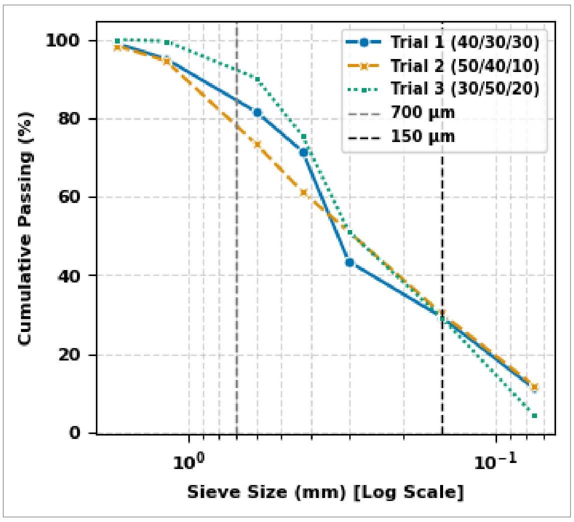

Figure 1: Effect of ball charge composition on the fine feed (1.7 mm - 700 µm) product PSD.

The optimization path for a single feed type is shown in Figure 1, while Figure 2 is designed to highlight the most important trade-off that this research must deal with: reaching the target size while limiting the production of fines. The figure intentionally contrasts the two most conclusive strategic outcomes to make the strongest possible case. It compares the ultimate, "precision" method of Trial 3, which used the optimized charge on fine feed, with the "brute force" method of Trial 2, which used a coarse ball charge on coarse feed. However, being a crucial stage in the optimization process, Trial 1's intermediate outcomes are not included in this comparison since these two endpoints offer the clearest and most convincing proof of why the successful, final methodology was chosen.

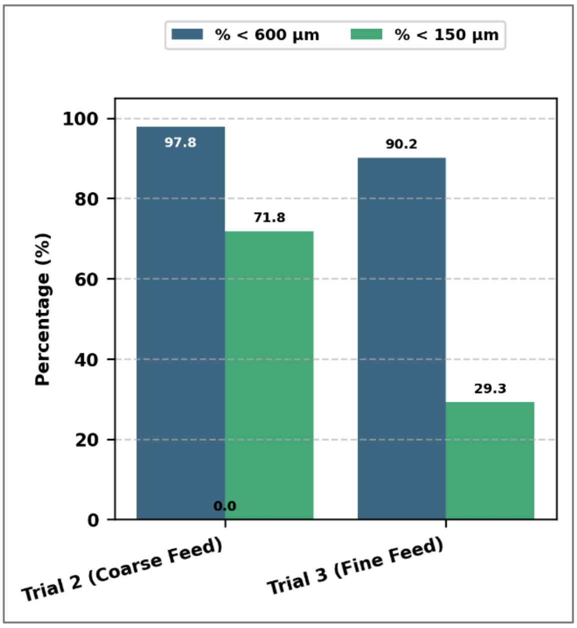

Figure 2: Comparison of key performance indicators for selected trials.

As seen in Figure 2, the high-impact conditions of Trial 2 on coarse feed yielded a very high yield of material below 600 µm (97.8%), however at the cost of exceptionally high and undesired fines generation (71.8%). In contrast, Trial 3's optimized strategy yielded a return that was nearly as high (90.2%), however it managed fines far better (29.3%). This comparison clearly shows that combining an optimized intermediate-weighted ball charge with a predefined fine feed is the most effective and successful way to produce glass-grade dolomite that satisfies standards.

4 Discussion

The findings from the experiments provide a clear description of systematic process optimization, successfully sidestepping the complex interaction of comminution mechanics to arrive at a practical solution to an emergency industrial problem. Treatment connects such experimental results with fundamental grinding theory.

4.1 The Foundational Role of Material Properties

The optimization began not at the mill, however with the raw material itself. The initial characterization of the varieties of dolomite, i.e., the AIV test, proved to be a critical decision gate. Selecting planar dolomite (AIV: 20.89%) instead of the more brittle crystal dolomite (AIV: 21.75%) was a beginning that led the way toward controlled grinding. A lower AIV signifies greater toughness, which enables the material to better withstand those initial, high-energy impacts in the mill without immediately shattering into too many, unwanted fines. This inherent property is most critical; it is an exercise in ineffectiveness to attempt to optimize a grinding circuit with an unsuitable, too-friable material. This finding underscores a valuable guideline for the industry: a thorough understanding of feed material characteristics is not an academic concern however a necessity for efficient and effective process design. The mechanical response and thus the grindability of Sri Lankan marbles are governed directly by the variation of their mineralogical texture, as noted by Madugalla & Pitawala [3].

4.2 Deconstructing Breakage: From Brute Force to Precision

The three trials demonstrate the rational progression of motion from broad, inefficient solutions to targeted, optimized solutions, revealing the underlying balance between impact and attrition forces governed by the ball charge.

The coarse ball charge (Trial 2) was a "brute force" approach with impact breakage predominance. As one would expect from theory [11], the high-impact energy of the large 60 mm balls shattered the coarsest feed very effectively.

However, the expense of this was disastrous, uncontrolled fracture, producing an unacceptable overflow of fines (71.8% <150 μm). This test clearly illustrates the law of diminishing returns in grinding; the energy was sufficient for initial breakage however too crude for the subsequent, more delicate work of breaking down intermediate particles.

The balanced charge (Trial 1) was an attempt at a more sophisticated approach. However, the relatively high proportion of small (30 mm) balls, while creating attrition, brought a second imbalance. The grind action was too aggressive to the fine end of the spectrum, again leading to over-processing and excessive fines in all feed sizes.

The optimal charge (Trial 3) is made possible by its planned balance. By charging the system with a higher proportion of 40 mm intermediate balls (50%), the system still carried sufficient impact energy from the 60 mm balls to initiate breakage while taking advantage of a large population of 40 mm balls to create controlled, incremental size reduction. The lower population of 30 mm balls provided the final "polishing" mechanism through attrition without being too aggressive. This "staged" breakage in one charge, where different media sizes are attacking different particle sizes, was found ideally suitable for the fine feed (1.7 mm - 700 μm). This result provides a practical demonstration of the core principle of efficient milling, which is to balance media and particle sizes during the entire breakage process [10], [11].

4.3 Strategic Feed Selection and the Case for Two-Stage Grinding

The decision to focus on finer feeds in the final trial was based on insights gained from the preliminary trials. The results clearly showed that it is not effective and impractical to try to satisfy the tight particle size requirements of the glass industry from a coarse feed in a single stage of ball milling. The huge quantity of impact energy required for initial breakage inevitably leads to over-grinding of the fragments thus formed. As Austin and Bagga [6] have pointed out, excessive fines can cushion particles and lower breakage rate to waste energy.

This research is the logical and necessary continuation to the paper by Gohulan et al. [4], which found out the deficiencies of the initial autogenous mill. The study and the earlier one form a comprehensive, plant-scale strategy of product optimization. The best way to a precision product is a two-stage process: initial size reduction in the autogenous mill and controlled secondary grinding in a ball mill with optimized load of feed and media. Such concerted intervention, whereby each machine operates in its best capacity, is the most efficient use of energy, which is directly related to the economic viability and ecological sustainability of the plant by reducing energy consumption and associated carbon emissions [12].

5 Conclusions

This work has successfully identified and validated key operating parameters for an improved grinding process for the production of dolomite to glass grade, providing a clear, fact-based foundation for addressing a significant industrial problem. Through systematic investigation of material properties, feed particle size distribution, and ball charge composition, this preliminary optimization study has integrated basic comminution theory into a productive industrial process framework.

The major findings of this research are definitive:

- The inherent physical properties of raw material practically define grindability. The selection of planar dolomite, which has greater toughness (AIV of 20.89%), was a critical decision that allowed size reduction control and prevented the formation of unwanted fines.
- A blend of the fine feed (1.7 mm - 700 µm) and the optimized, middle-weighted ball charge (30% 60 mm, 50% 40 mm, 20% 30 mm) achieved the optimal and most effective grinding performance. The synergistic blend resulted in a product with 90.2% passing 600 µm sieve size, bringing the process to the threshold of the 100% mark while having the maximum possible control on fines generation.
- Research also confirmed that there is no single "best" ball charge; it must be precisely matched to the feed size. This research shows that inefficiency is caused by maldistribution between media and feed through either too little breakage or over-grinding uncontrolled.
- The company's initiative to install a backup ball mill is validated by the analysis. An optimized two-stage process that consists of first crushing and then carefully regulated ball milling of a pre-classified feed is clearly more efficient for generating a product with required particle size requirements-a function for which a single-stage autogenous mill is inadequate.

In this investigation, the bridging of theoretical grinding regulations and actual industrial manufacturing needs were achieved. The study provides Metal Mix (Pvt) Ltd., a simple and actionable plan to optimize plant efficiency, meet stringent glass industry quality requirements, and reduce operating expenses significantly.

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