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EVALUATION OF A WET DISC-MILL SYSTEM FOR PRODUCTION OF FINE-GROUND MICA

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ABSTRACT

A prototype wet attrition disc mill was designed and operated in closed circuit at the MRL to grind mica. The mill utilized the principle of controlled "hydroplaning" between two flat discs acting upon an injected mica slurry. Low bulk density of the resulting mica product indicated that this technique showed superiority over previous systems. Final minus 325 mesh mica product gave a bulk density reading of 5.5 lbs/cu ft in one case. Comparison was made with other grinding systems, notably the USBM attrition grinder. The MRL disc mill will require additional research and development before emerging as a practical commercial device.

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BACKGROUND OF THIS RESEARCH

For perhaps the last twenty years, there has been produced from the pegmatite of the so-called tin-spodumene belt of central North Carolina a flotation-size (about 20 mesh) muscovite mica concentrate as a by-product of flotation operations whose primary product is spodumene. This mica side product has several unique characteristics. One is its extreme whiteness, which makes it very desirable from a quality standpoint. A second mineralogical characteristic, however, has made it difficult to sell. There has seemed to be no commercial fine-grinding technique in existence which could create from it a product which was sufficiently delaminated. Lack of delamination was reflected by high bulk density readings (pounds per cubic foot) when the fine-ground product was tested with a Scott Volumeter. This was also observable when the product was examined under a high-power microscope in comparison with like products ground from other micas. Particles of the latter could be seen to have a much higher aspect (breadth-to-thickness) ratio.

Reasons for this technical difficulty were set forth by a mineralogist, A. Frank Alsobrook, during his employment at the MRL. In 1966, Mr. Alsobrook described this mica as unweathered, formed at a relatively low temperature of crystallization but with a strong alkali bond. This resulted in a mica which was relatively soft, yet hard to delaminate. Thus, the usual grinding forces applied to it tended to fracture more, and delaminate less, than the same forces on many other commercial micas. The resulting ground product from this mica was then more blocky.

North Carolina produces the largest tonnage of mica of any state in the USA. It would presumably be to the State's economic benefit to solve this grinding problem and offer a mica product which is superior due to much lighter color. Additionally, a better grinding technique might then make possible mica products of even lower bulk density from the more usual micas. Mica-grinding experiments on this mica have been intermittently carried out at the Minerals Research Laboratory (MRL) since 1967, and a certain amount of data has been developed.

COMMERCIAL TECHNIQUES IN USE

Background

Qualitatively, a successful mica grinding system must effectively delaminate mica while performing a minimum of fracturing. The final product, containing flakes usually as large as 44 to 74 microns across, is required to have a bulk density usually between 7 and 10 pounds per cubic foot measured by Scott Volumeter, with the edges of the average mica flake in the product being relatively smooth, definite, and not crushed, crumpled, or ragged. The flat surfaces should also be smooth, and as close as possible to single-planed. The characteristics described are observable when a scanning electron microscope is used. The further a ground mica product varies from the stated characteristics, the lower the market price it generally commands. Two recognized qualities of ground mica--"slip" and "sheen"-- usually relate directly to the smoothness and planarity of the average particle of the product. If a ground mica feels slippery or "soapy" when rubbed between the fingers, and in addition presents a shiny appearance, it is said to have high slip and sheen. At this writing there is no direct objective measuring system for these characteristics, although it can be said that dry-grinding techniques for mica do not yield products equal in slip and sheen to wet-grinding techniques, and market prices reflect this. By the same token, wet grinding techniques are generally more expensive and sophisticated.

Lightness of color (generally determined by reflectance readings) is another usual quality criterion, with greater whiteness or brightness being desirable. Here, much depends on the raw material.

Dry Grinding

Two publications of the U. S. Department of the Interior enumerate certain known commerically used devices for dry-grinding mica.[1, 2] They are as follows:

- Buhr mill
- Rod mill
- Cage disintegrator
- Fluid energy mill (Majac)
- Attrition mill
- Hammer mill
- Micronizer

All the dry processes tend to fracture the mica or roughen its edges more than do the various wet processes: thus, dry ground mica (which usually lacks luster and feels "chalky") does not have the same end use applications as wet-ground.

Of the above grinder types, it seems likely that the hammer mill, the Majac, and the micronizer--operating in closed circuit with an air classifier--are today the most-used dry grinding devices.

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[1] "Mica, a Materials Survey," by Milford L. Skow (Washington), U. S. Department of the Interior, Bureau of Mines (1962) (Bureau of Mines Information Circular No. 8125).

[2] "Mica," by Frank G. Lesure, United States Mineral Resources, (Washington) U. S. Department of the Interior (1973) (Geological Survey Professional Paper 820).

Wet Grinding

Various rotating wet grinding mills employing cascading rod or ball-type media of metal, ceramic, or even wood, have been used. The present existence of such mills, operating commerically, is uncertain, but does not appear to be a major factor, at least in the U. S. A.

One principal type of wet grinder for mica is the so-called "Little Gem." This involves the force-feeding of mica slurry, under pressure by a rotating helix, into a closed chamber containing a rotating impeller with discharge from a constricted aperture.

A second principal wet-grinding technique used today on mica is the use of a mill known as a muller, chaser mill, or end-runner mill. Under present circumstances, this is a batch operation, although research toward making it continuous has been intermittently considered. The mechanism is as follows: two or more weighted rollers, with horizontal shafts more or less radial from a powered vertical shaft to which they are attached, rotate continuously around a bowl or tank which has been charged with a mixture of mica flakes and water. The rollers, slightly skewed from exact axis alignment toward the center shaft, exert a combination of fluctuating pressure and horizontal drag against the mica bed over which they roll. This can be said to cause a flexing action upon the average flake which, over a period of perhaps 5 to 8 hours, has its interlaminar bonds broken, with a minimum of fracturing. In addition, there is minimal crossways impingement between flakes, and so the product flake edges, viewed under a scanning electron microscope, are relatively free of "roughing up." After a given period of grinding, the mica "bed" is flushed out and hydroclassified and/or screened, and the oversize added, if desired, to a fresh grinding batch.

This grinding system embodies various "state of the art" techniques involving composition of rollers and mill floor, water addition, weight applied to rollers, etc. Users have claimed to the writer that this type mill cannot be used satisfactorily on flotation-size mica (20 mesh), but requires a charge of perhaps 8 mesh or coarser. The process is probably the most expensive in terms of product cost per ton. Coarse micas which can be ground by this means may yield a product as low as 7 lbs/ft^3bulk density.

A third--and most recent--technique for commercial attrition wet-grinding of mica has emerged as an outgrowth of research by the U. S. Bureau of Mines.[1] In this process, a charge of wet mineral slurry is ground in what might be described as a cylindrical pot containing a steel cage impactor mechanism. In addition to this mechanism, grinding media are added which are either too hard to fracture to any degree (quartz) or else too tough and flexible (nylon). With the impactor mechanism (stationary peripheral cage with central rotating impeller) in rapid motion and causing very intense bouncing and ricocheting of the media, grinding of the minerals charge occurs at a rapid rate in terms of the machine's chamber volume compared to that of other devices. This attrition mill can be engineered for continuous production in closed circuit.

Present state of the art indicates that nylon media in the USBM grinder (at the MRL) produce better fine-ground mica than do quartz media.[2] Possibly,

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[1] "Investigation of Operating Variables in the Attrition Grinding Process," by Martin H. Stanczyk and I. L. Feld (Washington) U. S. Dept. of the Interior, Bureau of Mines (1968) (Bureau of Mines Report of Investigation No. 7168).

[2] "Ultrafine Grinding of Several Industrial Minerals by the Attrition Grinding Process", by Martin L. Stanczyk and I. L. Feld (Washington) U. S. Dept. of the Interior, Bureau of Mines (1972) (Bureau of Mines Report of Investigations No. 7641).

the nylon cylinders or balls, upon impact against the mica flakes, fracture them less than quartz media, and at the same time flex the flakes and make them more subject to delamination. This grinding technique--with nylon media--might be expected to produce better fine-ground mica than if hard, cascading media were impacting by falling, but perhaps not as good a product as an end runner mill. Subjective evaluation at the MRL at this time rates slip and sheen of its products from the USBM grinder and the disc mill as fair to good. Several end runner mill products appear, by comparison, superior in this respect (see Table XI).

SAMPLE DESCRIPTION

Sample No. 4050 was a mica concentrate produced at Kings Mountain, North Carolina, at the plant of Foote Mineral Company. It was essentially 20 mesh and contained approximately 15% minus 200 mesh material. A certain amount of grit was present in the minus 140 mesh portion, and also in a small plus 20 mesh screen fraction. The behaviour of this sample when wetted indicated that either the flotation reagents (the oily or water-repellent ones) had been removed, or else the product had been concentrated by a means other than flotation, such as some sort of hydroclassification or gravity separation.

To reduce variable conditions, the entire sample was screened on 20 mesh (dry) and on 140 mesh (wet) in order to bring grit level as close as possible to zero. Following this double screening operation, the remaining sample, dried, weighed about 250 pounds. Table I gives screen analysis and bulk density of each screen fraction of the remaining sample after the screenings described.

TABLE I

SCREEN ANALYSIS AND BULK DENSITIES, SAMPLE NO. 4050

AFTER PRE-SCREENING FOR TESTS

U. S. SCREEN	PERCENT WEIGHT	LBS/CU. FT. BULK DENSITY OF SCREEN FRACTION
20-30	2.9	----
30-40	8.3	38.0
40-50	16.2	39.8
50-60	12.8	39.4
60-70	11.8	46.9
70-100	22.2	45.6
100-140	16.9	44.2
140-200	7.4	38.7
-200	1.5	----
TOTAL	100.0	43.7 (actual measurement)

The data of Table I confirm that this mica is noticeably less delaminated after coarse grinding to 20 mesh than, say, a typical mica concentrate obtained from Spruce Pine alaskite. For the latter, a usual bulk density figure is 28-32 pounds per cubic foot.

PREVIOUS GRINDING RESEARCH

Several samples of this spodumene-associated mica, gathered earlier and having different sample numbers, had been used for grinding research. This work was reported in MRL Reports 69-42-P and 71-16-P. In the first report cited, the principal information and data related to trial runs using a small batch grinder consisting of an Abbé jar mill shell with lead-filled ceramic rods in a holding frame. The rods slid (not cascaded) on a wet charge of flotation-size mica. Resulting fine-ground mica product in some cases measured as low as 5.9 pounds per cubic foot, and 5.4 pounds after calcining at 1200°F. These figures were actually lower than presently obtained by grinding this or any other mica, consulting known records. The second report (No. 71-16-P) which was more extensive, dealt with refined tests employing this same mill, and also with the following:

1. Techniques of mica evaluation, using these on different micas.
2. Discussion of the physical nature of differences among assorted fine-ground micas.
3. Possible construction of a commercial-size mill to produce the desired ground mica: its capacities and characteristics.

It should be stated here that, with more research having been done, the material written earlier under (3) is not now regarded as useful or valid, although justification for continuation of research along a different line appears to exist. Continuation of research along the lines of (1) and (2) is also presently seen as valuable.

DEVELOPMENT OF A DISC-TYPE MICA GRINDER

The grinding research performed previously, covered in the two reports just cited, led to the conclusion that two flat smooth surfaces, grinding against one another under limited pressure processing a wet mica slurry, were superior for this application to various grinding techniques involving impact or random pressure from assorted directions. Examples of the latter would be a pebble mill, a fluid energy mill, or a constricted-discharge pressure grinder such as the so-called "Little Gem." In these three cases, too much of the total grinding energy may move against the mica flakes along the wrong vectors, causing more fracturing and less delamination than is desirable--especially in the case of a mica such as Sample No. 4050. An end-runner mill (muller), which runs rollers around the inside of a mortar-shaped vessel containing a batch of packed wet mica, tends to warp and flex the mica flakes with minimum impact, but this apparatus appears limited in its ability to handle flotation-size mica as feed.

Since the original small grinder built from an Abbé mill shell embodied the principle of a hard round bar or rod sliding (not rotating) upon a flat surface, it was at first thought that it would be necessary to design a continuous mill having the same basic structural features. This idea was strengthened by some grinding data which appeared to show that a hard round surface in tangential contact (along a thin line) with a flat surface produced higher quality ground mica than a slightly flattened rod which was somewhat worn. It now appears that this was not really the case. When a vertical-shaft disc mill was constructed with a (lower) rotor consisting of a flat plate, plus an upper stator holding a large number of non-rotating hardened rods to drag on the rotor, it did not produce mica superior to a subsequent setup. That setup had two plates like an ordinary disc mill (but with certain special structural features).

The grinding arrangement having multiple rods for a stator rapidly developed flat surfaces, despite the fact that the rods were coated with tungsten carbide. The tungsten carbide coating of the rotor plate also wore through. In addition, the mica slurry washed around and evaded the grinding surfaces to an excessive degree, causing an extremely reduced grinding rate.

A series of brief random experiments followed, in order to empirically determine a new construction which would not wear out and would also prevent evasion of the grinding surfaces by the mica slurry. The arrangement finally installed for a series of tests consisted of a solid (lower) rotor plate covered with 1/4 inch urethane, and an upper stator plate which was essentially a flat disc of stainless steel, coated with tungsten carbide, with a hole in the center for feed input. The stator plate was constructed to rest freely upon the rotor, but prevented from rotating by peripheral stops. In addition, the stator was constructed to be evenly loaded with weights in order to explore the variable of pressure. Figure 1 illustrates schematically the basic structure of this mill.

DESCRIPTION OF THE DISC GRINDING SYSTEM

Variables Possible

The revised mill was designed to test certain variables in test runs. The variables related to the mill itself were as follows:

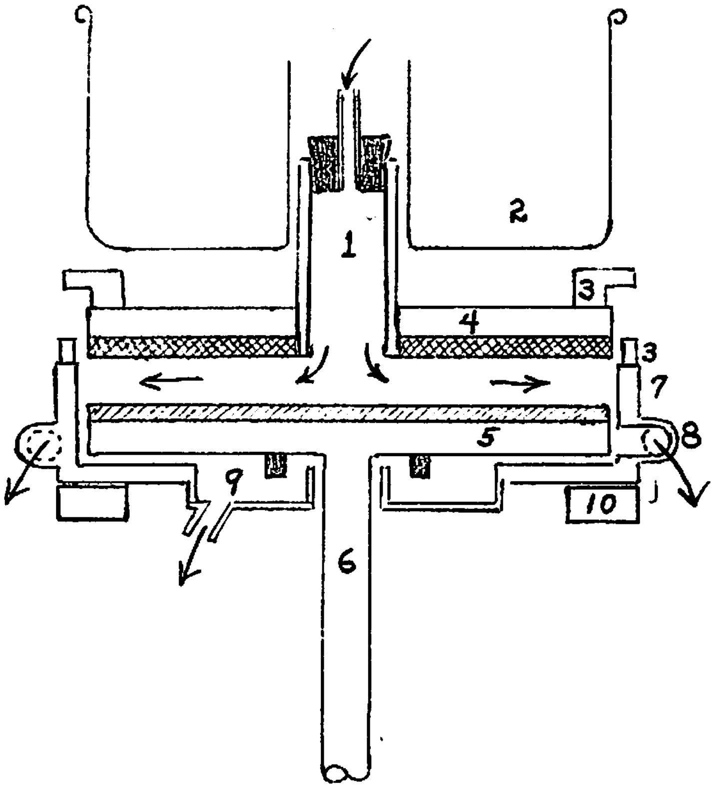
1. Speed of rotation
2. Grinding pressure
3. Grinding surfaces: composition and contours

Other variables could be tried by making changes in supporting apparatus such as the hydroclassifier, the pump feeding the mill, the belt feeder introducing head feed, and the controlled water supply. In this area, the variables could include:

1. Pulp density of mill feed
2. Feed rate into mill
3. Chemical additives such as dispersants, etc.

Figure 1

SCHEMATIC DIAGRAM OF "HYDROPLANE" DISC MILL FOR WET-GRINDINC MICA



Legend:

1. Feed intake pipe: stopper at top attaches to hose from pump.
2. Weight holder with walled opening in center.
3. Hardware for resting weight holder and for preventing stator rotation. 4 units, 90° apart.
4. Stator plate, 10 3/4 in. diameter - its surface is stainless steel, plated with tungsten carbide.
5. Rotor plate, 10 3/4 in. diameter - its surface is urethane.
6. Drive shaft. Bearings, etc., not shown.
7. Rotor shell.
8. Two opposed tangential feed discharge ports.
9. Pan with discharge pipe to catch surges.
10. Supporting frame.

Notes:

--Arrows show feed flow.
--Stator (4) and rotor (5) are separated during operation only by feed pulp passing through between them.

Figure 2 depicts the flowsheet in which the disc mill was the principal element. The total setup was a true pilot plant, although the production of ground mica was unusually small (about 300 grams per hour, maximum). The total flowsheet was used in some instances, and in others a batch-grind setup was employed.

Auxiliary Equipment

A brief description is offered regarding the equipment shown in Figure 2.

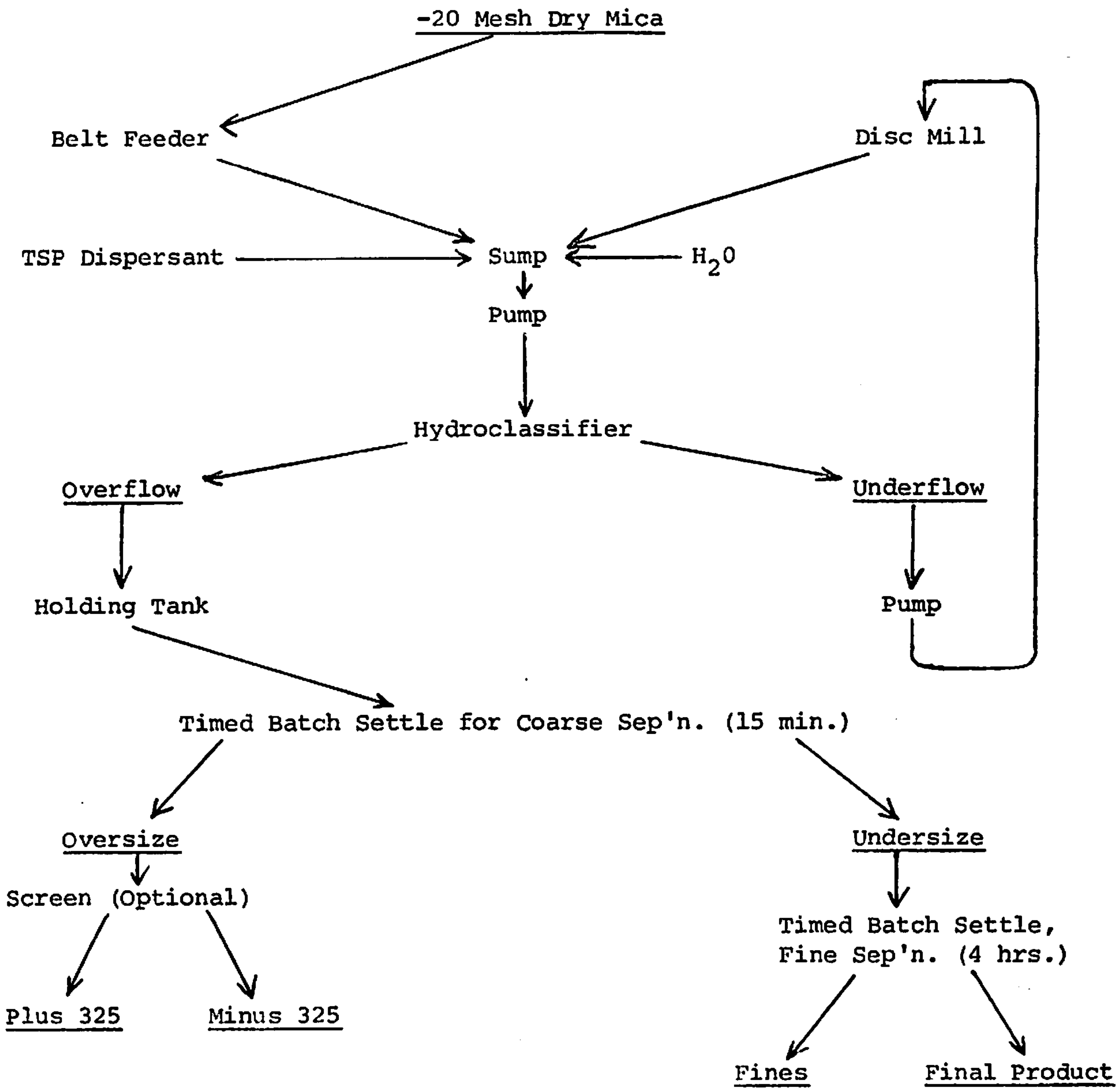
Belt feeder - This was a small dry feeder made by the MRL to meter out powder or fine granular material. Rate of feed was controlled by an adjustable lower aperture out of a hopper directly contacting the belt, and by adjusted rate of belt movement. The apparatus was designed to discharge between zero and 1000 grams per hour of minus 20 mesh dry quartz, mica, clay, or the like.

Pumps - Two tubing pumps, able to handle rubber or other flexible tubing of 5/16 inch inside diameter with a 1/16 inch wall, were used. The pumping system would reliably handle a maximum pulp density of 50% solids.

Tank Hydroclassifier - This was another special piece of MRL equipment. Overall length of the tank was 24 inches, and width 8 inches. Depth of water at the shallow end was 12 inches, and at the deep end 36 inches. Overflow was on one side only. The sloping bottom had a V-trough contour to center the underflow into a channel leading into a short rubber discharge hose at the lower end, 1/2 inch inside diameter. Four equally spaced movable vertical partitions, placed crossways, divided the classifier tank into 4 chambers. These extended to within a few inches of the bottom, and had the function of reducing turbulence from the down-flowing mica pulp being pumped in at the shallow end.

Figure 2

TOTAL FLOWSHEET RELATED TO DISC MILL



The discharge hose had, inserted into it, a 5/8 inch diameter helix made from an old wood drill, linked by a long vertical shaft to a small motor above. This was rotated at close to 45 RPM, and had the effect of controlling the rate of thickened underflow discharge. A tubing pump receiving the underflow for return to the mill guaranteed the desired underflow rate control.

A transparent plastic wall on the overflow side permitted visual observation of pulp within the hydroclassifier.

Figure 3 is a diagram of this apparatus.

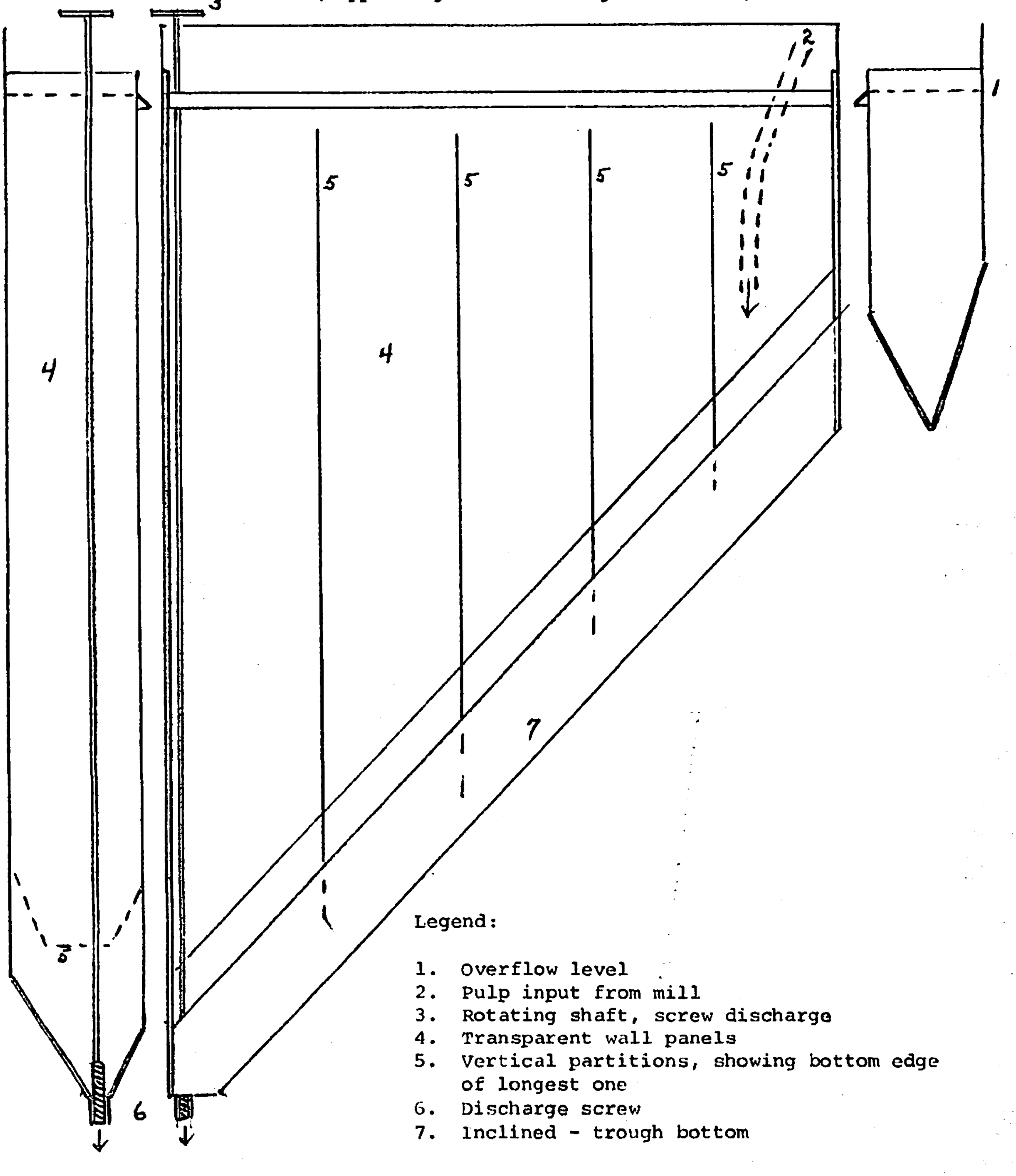
The depth of the mica pile awaiting underflow discharge at the bottom of the hydroclassifier was the factor which controlled the pulp density of the emerging discharge. This could be brought up to 65% solids, but grinding tests at above 50% solids were not possible because the receiving pump could not handle such thick pulp, nor would the pulp move through the tubing into the mill.

Grinding at 50% to 65% solids will require a different transmission system.

Unlike a rod mill or pebble mill, this disc mill permitted a very short average particle residence time: perhaps three to five seconds at most. Fresh feed and circulating load resided most of the time in the bottom of the hydroclassifier, where average particle residence time was on the order of 2 minutes. Thus, there appeared to be minimal chance for overgrinding due to long residence time per pass. However, because the hydroclassifier underflow (to the mill) had to be kept at 50% solids or lower, considerable fine-ground mica washed through with the water coming out in that stream. This caused overgrind from too many passes--observable from data to be cited.

The hydroclassifier overflow was run into a storage tank for dewatering for further (batch) hydroclassification or for evaluation as discharged.

Figure 3
DIAGRAM OF V-BOX HYDROCLASSIFIER
(Supporting frame and legs not shown)



Legend:

1. Overflow level
2. Pulp input from mill
3. Rotating shaft, screw discharge
4. Transparent wall panels
5. Vertical partitions, showing bottom edge of longest one
6. Discharge screw
7. Inclined - trough bottom

Water Supply - Fresh water was metered out of a constant head reservoir through two flowmeters. One stream went into the pump receiving the mill discharge, and the other directly into the hydroclassifier. The total water supply was used to regulate the rate of hydroclassifier overflow, and thus the coarseness of the overflowing ground mica product.

TEST RUNS WITH THE DISC GRINDER

General Types of Tests Run

The two main categories of tests run were (1) batch tests involving the continuous recycling of the same feed back into the mill by one tubing pump, and (2) the inclusion of the hydroclassifier described previously, which meant a true circulating load, along with introduction of fresh feed and continuous product removal. Some tests were run on portions of the sample which had been preground by the Snyder "shock-shatter" process (a stress technique using extreme sudden pressure changes in a steam chamber). In another test the sample was first very lightly ground in a pebble mill before disc milling. A third test involved pre-calcining.

It should be emphasized at this point that the total program described in this report could not be made a studied testing of carefully-controlled variables. Rather, it was a series of probing operations to find guidance for future research along definitive paths. The disc mill used embodied two unique and unexplored concepts. It appeared worthwhile to search empirically in various directions to see what, if any, extreme performance differentials could be discovered. This plan of action was further impelled by a final shortage of assigned project time.

Various mechanical problems which appeared in the setup and operation of this non-standard system required disproportionate time to solve, leaving too little for actual data-gathering operations.

Standard Wet Classification Technique

An empirical classification system was needed to concentrate the ground mica product, which had to be separated from the following:

1. Fines which represented overground feed.
2. Oversize.
3. Mica of correct product screen size, but still insufficiently delaminated.

A standard procedure evolved which included the following steps on a given sample containing fine-ground mica:

1. The sample was diluted to 1% solids or lower in a 6-gallon plastic tank filled to a depth of 12 inches.
2. Following thorough agitation, settling was allowed for 15 minutes, followed by careful decantation by siphoning with an upcurved intake. This step was performed twice, the decant pulp being flowed into two empty 6-gallon tanks.
3. Contents of the two tanks were allowed to settle for 4 hours and again decanted as previously.

Step 2, above, removed oversize plus sized but undelaminated material. Step 3 removed a fines fraction with the decant, leaving a final (settled) product approaching the characteristics of commercially ground fine mica in the minus 325 mesh range.

Consulting tabular data regarding the settling rate (under Stokes' Law) of quartz spheres in water, it can be calculated that the spherical <u>diameter</u>

equivalent of the mica product thus concentrated runs between 5 and 20 microns. Physical screening of such products showed, however, that they sometimes contained, by weight, as much as 3 percent mica larger than 325 mesh (44 microns). A Coulter Counter particle size analysis indicated in one case that the actual lower size cutoff on the product was on the order of 7 microns. In instances where a highly delaminated fine-ground mica is produced, such a discrepancy should be more pronounced than in the case of a product consisting of blocky particles.

Material finer in size than the product (Overflow, Step 3) was considered to represent overgrind: it varied in quantity according to test conditions.

Since any fine particles of mica having a blocky aspect would sink faster than flaky ones, it could be expected that they would report with the sinks or "underflow." This did occur, and it was always possible to screen out a minus 325 mesh fraction of sinks which had a significantly higher bulk density than the product (which had roughly the same size range). For example, the product might register 7 lbs./ft.^{3} bulk density while the minus 325 mesh sinks from the same test would give a reading of over 19 lbs./ft.^{3} The question arises: how much of this blocky fine mica can be further delaminated and how much will only fracture into fines when ground further?

In subsequent passages and table headings, the standard wet classification procedure just described will be referred to as "SWC."

It is regarded as likely that a classification step similar in effect to the above SWC procedure would be needed on a commercial basis; therefore, this procedure played an integral part in evaluations of this report.

Batch Tests, Varying Pressure

Initially, the disc mill was operated with two flat metal discs, and a charge of mica feed (See Table I) circulated through the mill which, as stated, retained the feed for only a few seconds. A tubing pump received the pulp by way of a sump and immediately pumped it back into the mill.

In this test series, constant factors were as follows:

1. Mill rpm = 180
2. Percent solids = 50
3. Dispersant = 1.0 lbs/T tetrasodium pyrophosphate
4. Pump return rate = 752 cc's per minute of pulp
5. Total mica charge = 400 grams

After grinding, the total charge was put through the SWC procedure.

Table II gives test data resulting from varying the weight on the (stator) head of the mill.

Discussion, Table II - The final test (TC6N) had to be cut short after one hour because the mill and the pulp became hot, with hazard of deterioration of rubber and plastic parts.

While operating under low pressure (TC3N and TC4N), the stator head of the mill exhibited a hydroplanning characteristic, similar to a slick tire on a wet highway. This was evident from the fact that the stop on the head was exerting very little rotational torque against the block on the shell (See Item 3, Legend, Figure 1). As increased weight was used in succeeding tests, torque increased also.

Data indicates that not much grinding took place until pressure on the head exceeded 1 psi. But it can also be observed that, under the conditions just stated, the final mica product deteriorated in quality as pressure increased, i. e., it measured higher in bulk density. Thus, it can be

TABLE II

RESULTS, PRESSURE VARIABLES, MICA MILL BATCH TESTS

Test No	Stator Weight Psi*	Weight Percent After S. W. C.			Ratio, Product/ Fines	Prod Bulk Dens (Lbs/Ft^3)	Hours Run	Prod Plus Fines: Grams/Hr
		Oversize	Product	Fines				
TC 3N	0.11	80.2	13.2	6.6	2.0	10.6	2½	35.6
TC 4N	0.18	79.6	12.6	7.8	1.6	10.8	2½	32.7
TC 2N	0.5	46.9	37.4	15.7	2.4	9.7	2½	84.9
TC 5N	1.28	47.0	33.1	19.9	1.7	12.3	2½	105.9
TC 6N	1.87	64.5	22.6	12.9	1.8	13.3	(1 hour only)	159.7

*Grinding area:
86 sq. in.

TABLE III

RESULTS, VARYING SPEED, MICA MILL BATCH TESTS

Test No	Rotor RPM	Weight Percent After S. W. C.			Ratio, Prod/ Fines	Prod Bulk Dens, (Lbs/Ft^3)	Hours Run	Prod Plus Fines: Grams/Hr
		Oversize	Prod	Fines				
108N	180	35.3	45.8	18.9	2.4	5.9	3	31.5
109N	360	17.9	39.4	42.7	0.9	6.1	3	42.2

surmised that, with added pressure, grinding energy went increasingly into fracturing, and less into delaminating of the mica.

Change of Mill Grinding Surfaces

At the conclusion of the preceding test series, it was found that the tungsten carbide surface of the rotor plate had worn away to some degree. As an experimental measure, a disc of virgin polyurethane, 1/4 inch thick, was substituted. A number of preliminary tests indicated that this caused no mechanical problems, and in addition the polyurethane exhibited almost no wear. All subsequent tests were then run with a tungsten carbide coated stator disc and a polyurethane rotor disc. When all test runs were completed (estimated operating time 60 hours), the polyurethane still retained much of its original glossy surface.

Batch Tests, Varying Speed

Using the new grinding surface setup, two tests were run at differing rotor speeds. Constant conditions were as follows:

1. Percent solids = 30
2. Dispersant = 1.0 lbs/T tetrasodium pyrophosphate
3. Pump return = 752 cc's per minute of pulp
4. Total mica charge = 150 grams
5. Stator pressure = 0.5 psi

Table III gives test data resulting from speed variation.

Discussion, Table III - Under the conditions, the increase in production of ground mica was less than expected. It appears likely that, assuming no malfunction, the thinner pulp of the mill feed (30% vs 50% solids) still allowed the mica particles to largely avoid one another (and the mill plates as well) when subjected to a more rapid grinding action. Bulk density of the mica was lower than when grinding was at higher solids (Table II). At the same time, a lesser net weight of mica was ground into product and fines than when feed pulp was 50% solids.

Comparing Test No. 108N, above, with Test No. TC 2N (Table II), the possibility exists that a production rate correction factor should be inserted to account for the difference in product bulk density between the two tests. Test No. 108N (Table III), while producing only 31.5 g./hr. of ground material, may reflect a higher ratio of properly-vectored grinding energy, since the bulk density of its product is 5.9 lbs./ft^3. compared to 9.7 lbs./ft^3. in TC 2N.

A Group of Closed Circuit Continuous Runs

Some closed circuit grinding tests were run next, using the hydroclassifier and the dry belt feeder (for fresh head feed) to set up a continuous operation. Numerous difficulties related to mechanics and coordination of apparatus ensued, and these invalidated a number of runs in their total aspect. A final run, which was fairly successful, yielded the best figures on production of ground mica and on the power required, given the state of the art at that point.

The continuous tests which it was possible to bring to a controlled finish shared a number of constants. These were as follows:

1. Use of a tungsten carbide stator and a urethane rotor.
2. Constant volume of pulp (2300 cc/min.) entering the mill.
3. Constant pressure on the stator head of 1.2 lbs/in^2
4. Constant hydroclassifier overflow of 1000 cc/min.

The accurate addition of tetrasodium pyrophosphate (dispersant) to the grinding pulp was not possible, but was held between 1 and 2 lbs./T. of fresh mica feed added.

Since a quick measurement of rate of grind could not be made (due to short runs), the addition of fresh mica could not always equal what left the system as product or fines. The belt feeder metered mica in at a constant weight, but in order to keep pulp density of hydroclassifier underflow constant into the mill during a given run, it was often necessary to dump in additional fresh mica by hand. Thus, hourly feed input figures must be proximate. In examining tabular data immediately following, it should be assumed that the mica added during the run was fairly equal to that which was removed as product or fines.

Table IV gives some data on a number of pilot plant type runs with continuous feed and discharge with closed-circuit grinding.

Discussion, Table IV - The data indicates, overall, that an acceptable mica product can be turned out over a fairly wide variation of conditions involving percent solids (33%-50%) and speed of rotation (260-400 rpm). There appears to be some correlation between bulk density of final product and percent solids of the grinding pulp. However, this could also be a function of the rate of solids flow through the mill.

The runs did not produce a visible correlation between the ratio of minus 325 product to fines and any of the variables shown. It is surmised that, for undetermined reasons, the circulating load (discharging as underflow from the hydroclassifier) varied considerably with respect to content of ground mica which should have overflowed into the holding tank. As stated before, the thin pulp of the underflow (35%-50% solids) meant a large amount of recirculating water carrying not only the proper oversize,

TABLE IV

TEST DATA ON CONTINUOUS RUNS

(Constant Conditions Cited Preceding)

Run No.	% Solids Grind	Mill RPM	Grams/Min Solids to Mill	Mica, Initial Chg	Hydro Residue	+325 Prod O-Size	Prod Fines, SWC	-325 Final Prod
N5-22-75	33	260	1029	2500 g.	2663 g.	39 g.	48 g.	78 g
N6-3-75	44	260	1394	3275 "	3586 "	21 "	42 "	36 "
N6-6-75	50	260	1669	3800 "	4217 "	46 "	68 "	150 "
N6-13-75	45	400	1437	3400 "	3608 "	7 "	238 "	246 "
N6-16-75	35	400	1032	2500 "	2788 "	4 "	76 "	147 "
N7-16-75	45	300	1437	3400 "	3571 "	23 "	203 "	165 "

Ratio, Final Prod/ Fines	Lbs/Ft^3 of Final -325	Mins Duration of Run	Grams/Hr Mica Prod Collected
1.6	6.6	128	59
0.9	7.1	98	48
2.2	7.5	209	63
1.0	6.8	169	171
1.9	6.2	84	160
0.8	7.1	120	184

but also a good quantity of mica which should have been removed in the overflow. This condition meant that, when a given run was completed, there remained in the hydroclassifier a portion of ground product which was not measured or reported in the data of this table. Thus, the column "Grams/Hr Mica Product Collected" should be regarded only as a comparative index of production rate. Time remaining for the project did not permit evaluation of "hydroclassifier residue" except in the last instance (Run N7-16-75), which is dealt with further under the sub-heading following this one.

Data on One Closed Circuit Run

The last run cited in Table IV (N7-16-75) was carried out with the intent of making a more detailed evaluation, including measurement of power consumption.

The run was carried out in the usual manner, and readings taken on a demand wattmeter attached to the mill alone. Operating conditions are here set forth:

Duration of Run - 120 Min

Mill RPM - 300

Pressure on stator head
1.2 psi

Wattage Readings

Free rotation, no pulp or pressure
225 w/hr
Circulating pulp, no pressure
231 w/hr
Grinding under stated conditions
462 w/hr

Percent solids, pulp into mill - 45%
Flow rate, pulp into mill - 2300 cc/min
Flow rate, solids into mill - 1437 g/min

Hydroclassifier overflow rate - 1000 cc/min
TSP dispersant: Added 3.5 g initially, then 1.0 cc/min of 5% sol'n.
System pH: 9.5

At the end of the two-hour run, all mica in the system was collected and processed for evaluation. Table V gives data.

TABLE V

QUANTITATIVE DATA, RUN N7-16-75

	Hydroclassifier Residue			Overflow to Holding Tank		
	SWC Oversize	SWC Product	SWC Fines	SWC Oversize	SWC Product	SWC Fines
Weight, grams	2762	218	49	38	301	203
Wt. pct. of total	77.3	6.1	1.4	1.1	8.4	5.7
Weight, -230 frac.	503	200		31	293	
Wt. pct. of total	14.1	5.6		0.8	8.2	
Lbs/ft^3, -230	22.6	8.3		11.1	6.5	
Weight, -325 frac.	235	144		23	165	
Wt. pct. of total	6.6	4.0		0.6	4.6	
Lbs/ft^3, -325	23.3	8.7		11.8	7.1	

Discussion, Table V - To arrive at an hourly production rate for this run, the following were added (refer again to Figure 2 if desired):

Hydroclassifier residue	S. W. C. Product, -325	144 grams
" "	S. W. C. Fines	49 "
Overflow to holding tank	S. W. C. Oversize, -325	23 "
" " " "	S. W. C. Product, -325	165 "
" " " "	S. W. C. Fines	203 "
	TOTAL, 2 HOURS:	584 grams

The minus 325 fraction of the S. W. C. oversize, hydroclassifier residue, was not included because, while it was size-reduced, it was obviously not delaminated (see high bulk density), and was yet to be ground into either product or fines. All the mica portions which were included in the rate calculation should have, under perfect conditions, reported to the holding tank, and assuming a correction of the thin pulp underflow problem described previously, should have comprised, in toto, a more favorable ratio of product to fines. Under the conditions of this run, the ratio of product to fines was 1.55 to 1, which differs from data on the ground mica from the holding tank alone (Table IV). It is judged, however, that too many fines were still produced.

The total production figure (584 grams) shows hourly production of 292 grams. The power expended was 462 watts per hour. Therefore, it may be said that the power used to grind 1 gram of mica was 1.58 watts, or 1.58 kwhr/kg. A figure of 1433 kwhr/T of ground mica is then calculated. Of this wattage, 716 kwhr., or 50%, was used to rotate the mill and propel the grinding pulp.

If, instead of minus 325 mesh, the product size is considered to be minus 230 mesh, then hourly production can be set down as 388 grams, and this in turn will result in a power figure reduced from 1433 to 1078 kwhr/T of product.

ADDITIONAL TESTS AND DATA, VARIED TECHNIQUES

Pebble Milling Combined with Disc Milling

When wet-ground in an Abbé pebble mill, this sample yielded a product of 15-17 lbs/ft^3. However, there was a question whether light pebble milling might do minimal grinding, but pre-stress the mica flakes, resulting in subsequent easier delamination. Two hundred grams of sample No. 4050 was lightly pebble milled at 30% solids in an 8-inch Abbé jar mill with 600 grams of porcelain balls close to 3/4-inch diameter. Grinding time was 5 minutes at 55 RPM. Following this, a 150-gram aliquot was batch-ground in the disc mill under these conditions:

174 RPM   30% Solids
0.2 PSI   2 lbs/T TSP (tetrasodium pyrophosphate)
3 Hours   Pulp throughput - 752 cc/min

This was a duplicate of an earlier test, grinding some sample which had no pre-milling. Table VI gives data.

TABLE VI

CHARACTERISTICS OF FEED AND PRODUCTS, AUXILIARY PEBBLE MILL GRINDING

	Original Sample	Pebble Milled Sample	Test 4050-106N (Sample Pebble-Milled, then Disc-Milled)	Test 4050-102N (Sample Disc-Milled Only)
Bulk Dens., Total Sample, Lbs/Ft^3	43.7	36.5	25.6	23.2
Bulk Dens., SWC Product	(No prod.)	(No prod.)	7.9	7.6
Percent of Feed, SWC Prod.	----	----	20.1	12.7
Percent of Feed, SWC Fines	----	----	12.7	7.0
% Prod. ÷ % Fines	----	----	1.6	1.8

Discussion, Table VI - In addition to the data of the table, it can be noted that, after pebble milling, the amount of minus 200 mesh mica increased from 1.5% in the initial sample to 11.6% in the pebble-milled sample. At the same time, the plus 40 fraction decreased from 11.2% to 4.3%. The 100-140 mesh fraction changed only from 16.9% to 16.4%.

Based on bulk density readings, there is some evidence that the pretreatment in the pebble mill might cause slightly poorer quality in the final product. However, the increase in production is significant. In the event that disc-milling as a single process turns out to consume too much power, a two-step series employing a pebble mill, then a disc mill, might be considered. Adjustment of pebble mill conditions to improve quality may be possible.

These tests were run before it was established that heavier pressure and higher speed were desirable for the disc mill.

Snyder "Shock-Shatter" Process Combined with Disc Milling

During this research project, facts regarding the Snyder process[1] appeared in the news media.

Briefly, the process embodies a pressurizing/depressurizing shock cycle created in a steam chamber pressure system.

Under the proper controls, rocks and minerals can be shattered by this treatment. Lone Star Industries of Brookfield, Connecticutt, was equipped to process small quantities of mineral sample by the Snyder process, and did the MRL the favor of processing two batches: one was put through the process sequence once, the other twice. It was stated by Mr. F. J. Smit, Minerals Processing Engineer in charge of the processing, that had the second pass been made only on the oversize from the first pass, there would have been fewer fines. However, the existing results provided very useful information.

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[1] Lane White, Senior Editor: "Shock-Shatter Process May Challenge Conventional Milling Technique," Engineering & Mining Journal, December, 1972.

The products returned by Lone Star Industries were evaluated by screen analysis and bulk density tests. Principal attention was given to the sample which received two passes. Portions of this sample were ground in the disc mill in order to see whether more or better product would result compared to grinding an untreated sample. One base test was again No. 102N, cited in Table VI. Grinding conditions were the same. Table VII-A gives pertinent data. A second test on the Snyder process product was run based on Test No. 108N (Table III), Table VII-B gives comparative data on that.

TABLE VII-A

FIRST EVALUATION, FEED AND PRODUCTS, AUXILIARY "SHOCK-SHATTER" GRINDING

	Original Sample	Sample after Double-Pass Snyder Process	Test 4050-104N Sample after Snyder Proc. (2X) plus Disc Mill	Test 102N (Base)
Bulk Dens., Total Sample, lbs/ft^3	43.7	27.7	26.8	23.2
Bulk Dens., SWC Product	(No Prod.)	12.5	8.1	7.6
Percent of Feed, SWC Prod.	----	11.9	12.5	12.7
Percent of Feed, SWC Fines	----	3.3	10.6	7.0
% Prod. ÷ % Fines	----	3.6	1.2	1.8

Discussion, Table VII-A - It should be noted that in this test and the next one, the Snyder process sample ground in the disc mill first had removed from it, by the SWC process, a portion of "product" and "fines" which was 15.2% of the original sample. There would have been no gain in keeping this in the grinding charge, and in addition, it was desired to measure and evaluate it.

The above data seem to indicate that the Snyder-processed mica did not have any notable added amenability to delamination or grinding in the disc mill, although the Snyder process does of itself produce a fairly acceptable fine-ground mica with bulk density a bit on the high side (12.5 lbs/ft^3). At the same time, it does not create a high level of fines. The high level of fines after both grinding processes were carried out is probably due to the presence of a quantity of fine mica before disc-milling which was not ground or delaminated. Roughly 20% of the Snyder-processed mica to the disc mill was minus 200 mesh, compared to 1.5% minus 200 mesh in the original sample.

TABLE VII-B

SECOND EVALUATION, FEED AND PRODUCTS, AUXILIARY "SHOCK-SHATTER" GRINDING

	Test 4050-111N: Sample after Snyder Proc. (2X) plus Disc Mill	Test 108N (Base)
Bulk Dens., Total Sample, Lbs/ft^3	26.2	26.3
Bulk Dens., SWC Product	5.5	5.9
Percent of Feed, SWC Product	46.3	45.8
Percent of Feed, SWC Fines	26.8	18.9
% Prod. ÷ % Fines	1.7	2.4

<u>Discussion, Table VII-B</u> - The small differences between the results of these two tests do not appear to point to any different conclusions than those reached from the previous tests (Table VII-A).

Conditions during disc milling probably caused the low bulk density of the product in both tests. These tests entailed relatively low pressure and rotor speed, low percent solids, and low rate of feed passing between the discs. Although rate of production was low (30-35 grams per hour), the tests give an indication of future variables to be investigated to attain low bulk density. It may be that the closeness of the discs during grinding (permitted by the low rate of feed throughput), plus the low pulp density, are important factors.

Since, in one test, the mica product after the Snyder process was slightly higher in bulk density, and in the other it was slightly lower, it is not possible to say that the process had any particular influence on that characteristic.

Calcining Combined with Disc Milling

A third pre-treatment technique was calcining some head sample at 1200°F for 24 hours, then grinding it in the disc mill. This probably altered the crystal structure of the mica, since the hydrous bond would be destroyed at that temperature. The mica was markedly darker in color after the calcining. Table VIII gives data on the disc-milling of this calcined sample. Again, the same grinding conditions were used as Test 102N.

TABLE VIII

CHARACTERISTICS OF FEED AND PRODUCTS, CALCINING STEP PLUS DISC-MILL GRIND

	Original Sample	Sample after Calcining	Test 4050-103N Sample after Calc plus Disc Mill	Test 102N (Base)
Bulk Dens., Total Sample, Lbs/ft^3	43.7	39.1	26.9	23.2
Bulk Dens., SWC Product	(No prod.)	(No prod.)	6.1	7.6
Percent of Feed, SWC Prod.	----	----	15.2	12.7
Percent of Feed, SWC Fines	----	----	12.7	7.0
% Prod. ÷ % Fines	----	----	1.2	1.8

Discussion, Table VIII - Calcining apparently caused more grinding, lower bulk density of product, and a higher ratio of fines. Given a good hydroclassification system, the latter might be avoidable. It is significant that 27.9% of the feed was ground after calcining compared to 19.7% in the base test.

Alternate Use of USBM Attrition Grinder

The MRL owns a small model of the USBM attrition grinder, discussed earlier under the heading "Commercial Techniques in Use." The model on hand was built precisely according to a blueprint furnished by the U. S. Bureau of Mines, and is intended for laboratory batch testing. This small scale apparatus is described in Bureau of Mines Report of Investigations No. 7168, published August 1968.[1] It is called the "five-inch diameter attrition grinder." Further description of this apparatus is not seen as useful at this time, except perhaps to say that in the MRL test to be cited, the rotor speed was 1600 rpm/1400 fpm (diam. 3 1/8-inch), and the rotor clearance from the cage was 1/8 inch. Grinding media used were small nylon cylinders, 0.1 x 0.1 inches. The grinder was charged with 1000 grams of nylon media, 1500 cc of H_2O, and 250 grams of head sample. Duration of grind was 10 minutes. Table IX gives data on this test.

TABLE IX

DATA, GRINDING TEST, USBM ATTRITION GRINDER

	Original Sample, Table I	Test No. 4050-113N Sample after Grinding (USBM Grinder)	Test No. 4050-102N (Base Test, Disc Mill)
Bulk Dens., Total Sample, Lbs/ft^3	43.7	23.4	23.2
Bulk Dens., SWC Product (-325)	(No prod.)	7.6	7.6
Percent of Feed, SWC Prod.	----	15.9	12.7
Percent of Feed, SWC Fines	----	6.3	7.0
% Prod. ÷ % Fines	----	2.5	1.8

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[1] "Investigation of Operating Variables in the Attrition Grinding Process," by Martin H. Stanczyk and I. L. Feld. (Washington) U. S. Dept. of the Interior, Bureau of Mines (1968) (Bureau of Mines Report of Investigations No. 7168).

Discussion, Table IX - Test No. 4050-102N, a batch test involving the disc mill, illustrates only a certain qualitative and quantitative similarity of products from two entirely different mills. Conditions for Test 102N were not optimum in grinding rate or power consumption. This could also be true of Test 113N with the USBM grinder.

Both tests also yielded a minus 325 mesh mica of high bulk density (low delamination) which was part of the SWC oversize; and it is again conjectural how much of this would ultimately grind into product and fines, respectively.

Additional Data, USBM Attrition Grinder

It was of some interest to develop further information on the comparative performance of the USBM grinder during the above test, especially regarding power consumption. The best power consumption data on the disc mill has been cited previously (Run N-7-16-76, Table V). This was a continuous, closed-circuit run, but final product and fines were measured, making possible the calculation of a theoretical kilowatt-hour-per-ton figure relating to ground mica. The same was possible with the USBM grinder.

Although it seems unwise to attach great significance at this stage to power figures for grinding, the figures are interesting as a point of departure, especially if research is continued on both types of grinder. Table X gives pertinent data.

Discussion, Table X - The figures cited here indicate that the order of magnitude of kilowatt hours per ton of product is the same with respect to the two mills. The fact that the disc mill apparently consumed somewhat less power per ton of product is not regarded as highly significant at this stage of research.

TABLE X

POWER CONSUMPTION DATA, DISC MILL AND USBM MICA GRINDER

	Run No. N-7-16-75 Disc Mill	Test No. 4050-113N USBM Attr Grinder
Power, No Load	0.23 kwhr	0.26 kwhr
Power, Pulp Circulating	0.24 kwhr	----
Power, Grinding	0.46 kwhr	0.64 kwhr
Grams Ground/hr., -325	292	336
" " " , -230	388	460
Kwhr. per kg. ground, -325	1.58	1.90
" " " " , -230	1.19	1.39
Kwhr. per ton, -325	1433 (685)*	1724 (1023)*
" " " , -230	1078 (516)*	1259 (748)*

*These figures state the extra power used for grinding, above the power required to run the apparatus with no grinding.

To give more perspective to these power figures, it is noted that, when the USBM attrition grinder was used to grind mica by that agency (which originally designed and built it), the reported power consumption figures[1] were frequently approximately one-quarter to one-third of the figures given in Table X. At present no complete explanation is apparent for this discrepancy. Several factors, however, may partially account for it:

1. In both of the preceding (MRL) tests, the weight of minus 325 (or minus 230) mesh undelaminated mica reporting with the "Oversize " in the SWC step was not included in the product weight. This fraction was of very high bulk density and was

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[1] "Ultrafine Grinding of Several Industrial Minerals by the Attrition-Grinding Process," by Martin L. Stanczyk and I. L. Feld (Washington) U. S. Dept. of the Interior, Bureau of Mines (1972) (Bureau of Mines Report of Investigations No. 7641).

cited earlier as incompletely ground. In the USBM tests, all of the minus 325 was included as product. The total minus 325 mesh fraction produced by the disc mill came to 410 grams per hour instead of 292 grams. This figure would change the kwhr/T calculation from 1433 to 1020, with corresponding reduction of net power for grinding from 685 to 272 kwhr/T. On the same basis, the USBM grinder produced 570 grams per hour instead of 336, and so the respective power consumption figures might be reduced from 1724 to 1016 kwhr/T, with net grinding power reduced from 1023 to 315 kwhr/T. As between the two mills at the MRL, comparable grinding figures remain at close to the same level.

2. The mica products from the MRL tests were of considerably lower bulk density (7.6 lbs/ft^3 or less) than the USBM products (roughly 11.4 to 12.7 lbs/ft^3), indicating that the minus 325 products from the MRL tests had received additional delamination.

3. Data published by USBM referred to tests employing a 10-inch diameter machine (not 5-inch), and also using Ottawa sand grinding media instead of nylon. There is a possibility that the larger the model of the USBM grinder, the more efficient it is in terms of power consumption per ton of product, up to some optimum point of 10 inches diameter or larger. This has been true of many pieces of mineral processing equipment, including mills. If this is true of the USBM grinder, it may likewise be true of the disc mill. In addition, the power factor may be affected by use of nylon media, as opposed to quartz sand.

Additional research will be needed on both the USBM attrition grinder and an improved disc mill to resolve these questions related to power consumption.

SUMMARY

A sample of 20 mesh muscovite concentrate from North Carolina, having the characteristics of extreme whiteness plus comparative difficulty of delamination, was subjected to a series of grinding tests principally involving the use of a disc mill designed and constructed at the Minerals Research Laboratory. The disc mill had these unique characteristics:

1. Disc surfaces sufficiently flat and smooth that water or thin mica slurry, when pumped between the discs (with one rotating), created a controllable hydroplaning or "water wedge" effect.
2. One disc surface composed of polyurethane, and the other of stainless steel coated with tungsten carbide.

The choice of the disc surfaces was by chance, having been empirically tried out following failure of another rotating grinding system on the same mill assembly.

The disc mill was operated under varying conditions to determine the importance of such factors as grinding pressure, speed of mill rotation, rate of feed throughput, and pulp density of feed. It was also operated on both a batch and a continuous basis, the latter being in closed circuit with a hydroclassifying tank.

Various factors made a wide range of controlled conditions difficult, but certain data was developed. As regards the disc mill alone, the following facts emerged:

1. Under the given conditions, a minus 325 mesh ground mica could be produced having a bulk density as low as 5.5 pounds per cubic foot. Bulk density readings in the 6-7 pound/ft^3 range were frequently obtained under varying conditions.
2. Operation of the mill at thick solids (50%) and increasingly high pressure (up to 1.9 lbs/in^2) resulted in a product of increasingly higher bulk density.
3. The use of a polyurethane grinding surface resulted in no lower quality in the mica product; and in addition, this plastic evidenced less wear, with extended use, than did a grinding surface of steel or tungsten carbide.
4. An increase in rotational speed appeared to have no significant effect on product quality, but increased the hourly production.
5. Under the conditions which were tried, the mill produced a certain amount of fine-ground mica which had not been delaminated to the same extent as a product which could be concentrated by means of a batch settling technique. Given further treatment, this heavy mica may become either delaminated product or overground fines.

Portions of the mica sample which had been pretreated in various ways were also ground in the disc mill, and these facts emerged:

1. The use of light pebble milling on the sample prior to disc-milling appears to cause the mica to be ground at a faster rate, with little appreciable quality loss.
2. The Snyder "shock shatter" process, while of itself creating some acceptable fine-ground product, does not seem to render the remaining oversize amenable to more rapid grinding, nor does it contribute to better product from the disc mill.

3. A calcining step prior to grinding causes an increase in the production rate of ground mica and in addition lowers the bulk density of the product. However, somewhat more fines also result.
4. Grinding tests comparing the performance of the MRL disc mill with the 5-inch size model of the USBM attrition grinder, using nylon media, gave data indicating that the qualitative and quantitative performance of the respective mills was close. Power consumption of the two mills (kwhr/T of product) was also quite close although the USBM power consumption figures quoted on a larger version of their grinder were much lower than any obtained during tests at the MRL.

CONCLUSIONS

In light of products and data obtained from a series of preliminary tests, it appears that a disc mill, grinding a wet mica slurry, is a viable possibility for grinding high-quality mica. The MRL disc mill produced a fine ground mica of acceptable bulk density from a flotation size mica which until now could not be properly delaminated. It also ground this same difficult mica to a bulk density which is lower than any other fine ground mica product on record. Table XI gives the bulk densities of some present high-quality commercial offerings. Bulk densities were measured at the Laboratory.

Operated for only one comparative test, a USBM attrition mill, using nylon media, also ground a very good product from the same mica. Therefore, this apparatus is also regarded as desirable for use in further research.

TABLE XI

CHARACTERISTICS, COMMERCIAL WET-GROUND MICAS VS MRL-GROUND SAMPLE

Sample No.	Description & Source	Lbs/Ft^3 Bulk Dens., -325 Frac	Apparent Slip & Sheen	Mill Used
4050	As described (Test 108N)	5.5	Fair to good	MRL wet disc mill
4050	As described	7.6	Fair to good	USBM attrition grinder
3836	Wet-ground, Company "A"	9.5	Superior	End-runner mill
3840	Wet-ground, Company "B"	9.7	Superior	End-runner mill
----	Wet-ground, Company "C"	8.1	Superior	End-runner mill

Of the presently used techniques for wet-grinding mica, the disc mill and the USBM attrition grinder may have certain advantages, aside from quality of product. Table XII tabulates the characteristics of certain wet-grinding techniques already mentioned.

TABLE XII

MRL DISC MILL CHARACTERISTICS VS COMMERCIAL MICA WET-GRINDING PROCESSES

Name of Process	Media Used	Use of Heat, Steam, or Pressure	Batch or Continuous	Ability to Process 20-Mesh Mica
MRL Disc Mill	None	Pressure on feed & discs	Continuous	Yes
End Runner Mill	None	Mechanical pressure of rollers	Batch	Limited
USBM Attrition	Quartz or nylon: (must be recirculated)	None	Continuous	Yes
"Little Gem"	None	Pressure	Continuous	Yes

RECOMMENDATIONS

It is recommended that research be continued on the fine-grinding of mica, with the principal research centered on a new, re-designed disc mill, and the USBM attrition grinder, probably using resilient media of nylon or other plastic.

In conjunction with this, it is recommended that a research program be resumed to establish additional objective criteria for evaluating fine ground mica. A previous project (JPN No. 14, June 1971), suspended for revision, can be reactivated, and should include the following:

1. Research to adapt presently existing, recognized laboratory apparatus (for measuring sliding friction) to the evaluation of the characteristic known as "slip."
2. Research to correlate the characteristic known as "sheen" with angular light reflectance, using established available instrumentation.
3. Use of a scanning electron microscope to correlate general flake characteristics of fine-ground mica with "slip," "sheen," bulk density, and aspect ratio.
4. Use of the Laboratory's Warman Cyclosizer toward determining possible correlation between quantitative separations by that apparatus and bulk density.
5. The use of surface area determinations in evaluating ground mica.

Given improved quality measuring tools, it will then be possible to appraise all mica products with greater accuracy and authority, and make MRL data, samples, and proposals regarding ground mica more useful to interested parties.

The improvised disc mill used by the MRL up to the time of this writing should be replaced with one having these capabilities:

1. RPM capability up to 5000, assuming 12-inch discs.
2. Horizontal shaft rotation.
3. Interchangeable discs of different materials.
4. Adjustable pressure on feed input from 0.2 to 5.0 psi, handling pulp density as high as 60% solids, with variable input rate.
5. Adjustable pressure on discs to correspond with feed pressure.
6. A supporting system involving efficient hydroclassification and filtration to operate a closed circuit and to handle the ground product.

This improved mill system can give valid research data on the wet disc-grinding of mica, emphasizing the phenomenon of hydroplaning, which appears to play a useful role. In addition, it can yield accurate information regarding the following:

1. Power required to grind 1 ton of mica to a given quality standard.
2. Optimum combination of grinding variables: speed, pressure, pulp density, etc., to increase production and improve quality.
3. Possible use of chemical additives to improve grinding efficiency (make the pulp drag or slip more, etc.).

Finally, such a mill should be useable on a practical basis for operating demonstrations, plus grinding adequate quantities of mica to offer as samples to industry.