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Muller Mixing of Bentonite and Iron Ore Concentrate at Cornwall

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By means of laboratory balling tests and a procedure for determining bentonite concentration in a green ball, the present study revealed that the bentonite savings by mulling concentrate and bentonite prior to balling was sufficient to warrant installation of a full-size unit in a pellet plant. On the basis of this work, a muller was put on stream at Bethlehem Steel Corp.'s Cornwall pellet plant in June 1969, and has operated continuously since then. Plant tests showed that the use of the muller resulted in bentonite savings of about 50% without any loss of green, dry, and fired ball quality. Virtually no maintenance problems have been encountered. This information is important to future pelletizing operations both from the standpoint of product quality and economics.

Previous studies[1-3] had demonstrated the strong dependence of pellet strength on the degree of mixing of the iron ore concentrate and bentonite binder. The degree of mixing was also directly linked with the uniformity of ball and pellet properties. These findings point to the need for more thorough bentonite-concentrate mixing than is normally employed in commercial operations, since improved mixing would improve ball uniformity and at the same time reduce bentonite consumption.

In the early stages of the present laboratory test program, we evaluated mixing and other techniques in terms of a more economic use of bentonite as an iron ore pellet binder. We found that to save bentonite or, conversely, to improve ball quality it was not sufficient to simply improve mixing. Test results showed that the best ball properties could be attained only when the bentonite-concentrate-water mixture was subjected to the compressing shearing forces provided by mulling.

Before a muller could be installed in a pellet plant, however, it was necessary to determine experimentally the minimum retention time in the muller and the bentonite savings that could be expected from mulling pellet quality. The main reason for plant testing a muller was to look to the needs of future pellet plants, because high-quality bentonite is becoming scarce and its cost is increasing.

Laboratory Test Program

The two basic purposes of the initial experimental program were:

1. To determine the minimum mulling time required to provide ball strength of an acceptable level at a minimum bentonite content in order to arrive at the correct size muller to be purchased for installation in the pellet plant.

2. To provide data on bentonite savings that would be made possible by mulling the concentrate and bentonite as opposed to the current plant-mixing practice.

Test Materials: The iron ore concentrates used in this investigation were two physically and chemically similar magnetite concentrates from Bethlehem Steel Corp.'s Grace and Cornwall pellet plants. They are normally ground to less than 75% -325 mesh and a Blaine specific surface of 1200 sq. cm. per g. The binder was a commercial high-swelling Wyoming bentonite.

Test Procedures: The laboratory procedure for preparing green balls for use in the tests to determine minimum mulling time and potential bentonite savings was as follows:

1. 2500 g of iron ore concentrate is mixed for 10 min. in a Twin-Shell blender with the desired amount of bentonite.

2. The mixture is dry-mulled for 15 sec. in an 18-in. dia. Simpson intensive Mix-Muller. Then 305 cc. of distilled water is added in 10 sec. and the material is mulled for the desired length of time.

3. The concentrate is passed through a chopper to break any wet lumps.

4. 200 seed pellets prepared from the material to be balled and sized to -4 +6 mesh dia. are moistened and added to at 16-in. dia. rubber airplane tire rotating at 50 rpm.

5. 2000 g of the wet-mixed concentrate is added directly to the seeds in 3 min. When all the concentrate is added, the balls are rolled an additional 30 sec.

6. The finished balls are sized to between 1/2 and 7/16 in. for testing.

Where samples of wet concentrate containing bentonite were obtained from the plant, as in the case where the minimum mulling time was determined, processing was started at Step 2.

Immediately after balling, 10-in. green drop and green compression tests were carried out. Later, after the moisture content of the balls was determined, the dry compression test was run. These procedures are described in Ref. 4. For the laboratory test program, although green ball strength was routinely measured, the dry strength served as the main measurement of bentonite effectiveness. The technique for determining the bentonite content of the dry balls is the settling test procedure described in Ref. 1.

Determination of Minimum Mulling Time: To determine minimum mulling time, five samples of concentrate containing bentonite were taken in rapid succession from the conveyor belt ahead of the balling cone at the Grace plant. The samples were taken to the laboratory, and each was mulled for a different length of time prior to balling in a laboratory tire. After the balls were tested for strength, the average bentonite content of each batch was determined. The bentonite contents, shown in the parentheses near each point on the curve in Figure 1, varied widely. This variation in the bentonite content of plant samples is accommodated by plotting bentonite effectiveness, i.e., the average dry strength of the balls per unit of contained bentonite against mulling time.

Our studies – for example, the results shown in Figure 2 – have shown that the effectiveness of bentonite as a binder is somewhat dependent on the concentration of the bentonite in the balls so that the curve in Figure 1 should more properly be shown as a band. However, to obtain sufficient plant data to show a band in Figure 1 would have required extensive sampling and testing, and since it is obvious that most of the improvement in dry strength is achieved during the first minute of mulling, 1-min. mulling time was used in subsequent tests.

Estimating Potential Bentonite Savings: Bentonite savings was estimated by comparing a curve of ball strength vs. bentonite concentration for 1-min. mulling time against the strength and

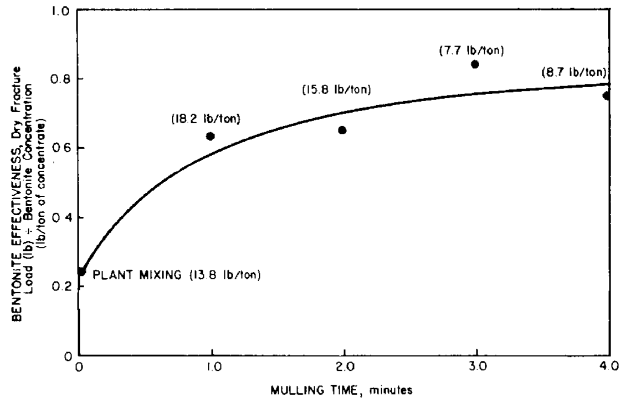


Fig. 1—Pellet dry fracture load per unit of bentonite concentration for Grace concentrate. Bentonite concentration given in parentheses.

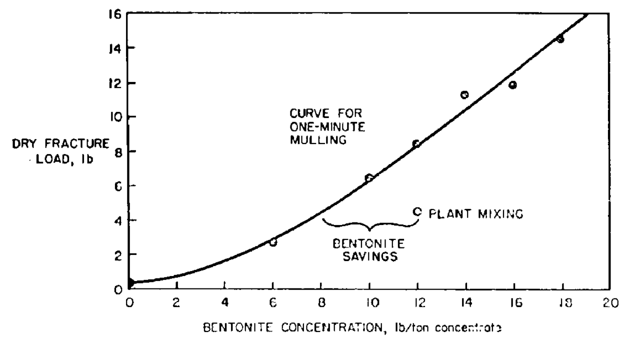


Fig. 2—Bentonite savings; 1-min mulling curve vs. plant mixing for Cornwall balls (laboratory balling).

bentonite content of balls made from plant-mixed bentonite and concentrate. The 1-min. mulling curve was obtained using the following samples obtained from the Cornwall pellet plant: concentrate containing no bentonite, bentonite, and concentrate containing bentonite.

The sample of concentrate without bentonite was dried and split into six subsamples. Bentonite was added to these samples to cover the concentration range up to 18 lb. per ton. Based on the results of the previous tests, each sample was mulled for 1 min. prior to balling in the laboratory tire. The sample of concentrate containing bentonite that was mixed in the plant was also balled with this group, and, after testing of the balls for strength, the average bentonite content of the batch was determined. These results are plotted in Figure 2, which shows that using Cornwall concentrate balls containing 12 lb. per ton of plant-mixed bentonite that had been mulled for 1 min. That is, at this strength mulling results in a saving of 4 lb. of bentonite per ton of concentrate. The saving at Grace was slightly more favorable.

As laboratory tests, these results could not of course provide any indication as to what maintenance or horsepower requirements might be expected from a commercial-sized muller operating day in and day out in an iron ore pellet plant. It was concluded, however, that the laboratory test results looked promising enough to put a full-sized muller on stream.

Plant Test Program

On the basis of the laboratory test results, an extended plant test program was instituted to evaluate the effectiveness of muller mixing in terms of bentonite consumption and equipment maintenance. Accordingly, a mulling unit was installed at Bethlehem Steel's Cornwall pellet plant at Cornwall, PA. The specific aims of these plant tests were to determine: 1) the minimum acceptable bentonite level required to provide the same strength of green balls and pellets by mulling as is obtained under normal plant-mixing conditions, and (2) the bentonite savings on the basis of several months of continuous service.

Based on discussions with Simpson Technologies Corporation, it was decided to install a Model 215G two-pan continuous muller, which was equipped with a 40 hp motor, tungsten carbide-coated plows and plow straps, an automatic lubrication system, and a dust hood. On June 10, 1969, the muller was put on stream ahead of the No. 6 balling cone that feeds Cornwall's No. 3 shaft furnace. The furnaces at Cornwall are fed by two balling cones that each handle about 27 dry net tph of magnetite concentrate. The concentrate and bentonite fed to No. 5 balling cone on the No. 3 shaft furnace and the feed to the other furnaces are mixed by conventional plant mixers. Prior to mixing and balling the magnetite concentrate is ground to between 60 and 75% -325 mesh, depending on the throughput desired, and filtering can lower concentrate moisture to about 8%.

Table 1 contains a summary of two plant tests carried out at Cornwall to evaluate the operation of the muller. The results shown are typical of those obtained during the first months of muller operation. Test No. 1, which took place about two weeks after the muller was installed, was carried out during two 8-hr. shifts on consecutive days. In this test, the muller operation was compared with plant mixing ahead of the No. 5 balling cone that also feeds No. 3 shaft furnace. On the first day of the test the bentonite feeders to both the plant mixer and the muller were adjusted to produce balls with a 4-lb. dry strength, which from past experience is an acceptable dry strength for survival of the balls in the Cornwall shaft furnaces.

It was found that to make balls of equal dry strength at acceptable levels of 4 lbs. and above, muller mixing required only half the amount of bentonite that was needed for plant mixing. For example, for the 4-lb. strength requirement in Test No. 1, the savings provided by mulling was 4.6 lb. per ton of concentrate. Fired pellet quality was compared by testing balls from both lines that had been dropped in nichrome wire baskets through furnace No. 3. All of the pellets tested were of acceptable quality, and there was no noticeable difference between the 1lb. tumble and compression test results. On the second day of Test No. 1 the bentonite feed rate ahead of the plant mixer was increased slightly, and the green ball properties improved accordingly.

Table 1. Physical Properties of Green* Balls and Fired Pellets

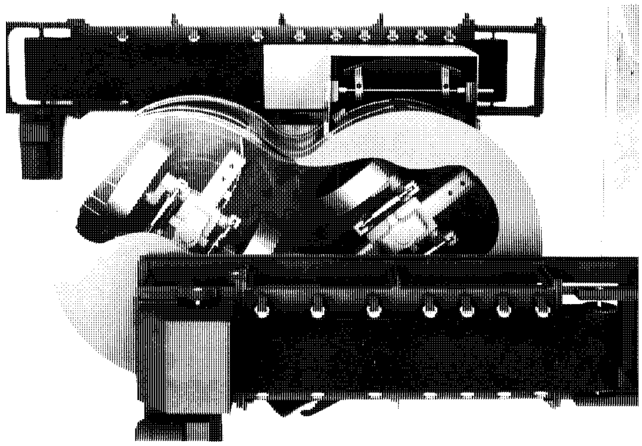
	Test No. 1				Test No. 2	
	First Day		Second Day		One Day Test	
	Plant	Muller	Plant	Muller	Plant	Muller
Concentrate Grind, % −325 Mesh	73.1	73.1	74.0	73.9	70.5	71.4
Bentonite Concentration, Lb per Dry Ton	9.0	4.4	11.5	4.7	11.3	5.1
Green Ball Properties						
Fracture Load, Lb						
Dry	4.1	4.0	6.7	4.2	5.3	5.3
Green	1.61	1.70	1.95	1.58	1.70	1.71
No. of 18-In. Drops	5.3	4.0	5.3	3.6	5.7	6.2
Ball Moisture, %	9.3	8.6	9.3	8.6	9.7	8.9
Pellet Properties						
Peak Temperature, °F	2250	2250	—	—	2350	2350
1-Lb Tumble, % + ¼-In.	93.7	93.1	—	—	98.0	96.2
Compression, Lb (Average)	403	505	—	—	368	346

* Balls sized to − ½ + 7/16 in. diam.

Test No. 2, which took place about 6 months after Test No. 1, was carried out during one 8 hour shift, and in this case the muller operation was compared with plant mixing ahead of cone 4, which feeds furnace No. 2. In both this test and Test No. 1 the green ball properties shown in the table are the average values obtained from three sets of samples taken during each shift. To determine the bentonite savings at a higher ball strength, the bentonite feed rate was adjusted on both lines until the dry ball strength was equal and over 5 lb. As the data for Test No. 2 show, to make balls having a dry strength of 5.3 lb. the muller required a bentonite feed rate of only 5.1 lb. per ton of concentrate while the plant mixer needed 11.3 lb. per ton, representing a 55% savings in bentonite. Rather than compare the quality of balls fired at the plant as was done in the case of Test No. 1, balls were taken from the plant to the laboratory, where they were fired in an Allis-Chalmers pot grate furnace. The resulting pellet qualities from both types of mixing were again good and very nearly equal.

During both Test Nos. 1 and 2 sieve analyses were run on the green balls to determine the uniformity of the balls produced by mulling. This was done because it was thought that if mulling distributed the bentonite and water more uniformly throughout the concentrate, the resulting balls would be sized more closely. Although no difference was found between mulling and plant mixing in this respect, the fact that the muller periodically discharges muller cake may have masked any improvement in ball size distribution.

During these tests, because of the limiting capacity of the balling cone, it was not possible to determine the maximum capacity of



Plan View - Typical Installation

the muller. However, no balling or muller problems were encountered during short runs at concentrate feed rates up to 34 dry net tph.

Economics of Muller Mixing

The plant test program provided us with data on which to base an estimate of the economics of muller mixing in terms of design features relating to the muller and the number of furnaces involved. In addition, there are the specifics of maintenance and power that also affect the economics of muller mixing. Finally, there are considerations of a general nature such as the increasing use of low-grade ores which require bentonite binders, and the future quality and cost of bentonite.

Bentonite Savings: Bentonite savings were calculated based on the first six months operating data. During that period, covering 3400 operating hrs, 50% less bentonite was used on the muller line, with no decrease in ball or pellet quality. During the six-month period, the bentonite feed rate to the lines using conventional mixing varied between 10 and 14 lb. per ton and the bentonite feed rate to the muller varied between 4 and 8 lbs. per ton. The average concentrate feed rate to the muller was 27.2 dry net tph. Two methods were used to calculate bentonite savings and the results checked closely. One method was based on daily production data and the other was based on monthly bentonite bin inventories.

When looking at the overall economics of mulling, consideration should be given to the fact that, at Cornwall, the muller turned out to be larger than what was needed for the one line. Still another approach to be considered is that one larger muller could serve more than one furnace. Over and above considerations dealing with the relation of muller size and/or number of mullers to plant requirements, there are external factors that affect the economic picture. For example, on the one hand, high-quality bentonite is becoming scarcer and will become accordingly more expensive and, on the other hand, as the iron ore industry increases it pelletizing capacity, more bentonite will be needed to maintain ball and pellet quality. Also, freight rates, which account for the major portion of the bentonite price, will continue to increase.

Maintenance: Although one year of operation is not long enough to accurately estimate maintenance costs, some projections can be made based on the costs incurred to date and the results of periodic inspections of the equipment. During the first year of operation the muller was down due to muller-type problems only 10 hrs. and the cost of parts was minimal. Inspection of the muller, however, showed that the four plows would need replacing about once a year. It was estimated that the set of plows could be replaced during one shift which is the length of normally scheduled downtime. For the first year of operation, the maintenance cost for parts was estimated to be $0.0037 per dry net ton of concentrate. To arrive at a total maintenance cost at Cornwall, additional factors must be considered. First, the cost of labor should be included and second, some additional factoring will be needed because sooner or later other major parts besides plows will need replacing.

Power: In determining the economic value of the bentonite savings resulting from muller, the power requirement for the muller should be taken into consideration. Under the test conditions, which were typical of normal plant operating conditions, the muller drew up to 19 kw at a concentrate feed rate of 29 dry net tph and a filter-cake moisture of 8.9%. Although this figure is higher than the power used for plant mixing at Cornwall, the bentonite savings provided by mulling by far outweigh the additional cost of power.

Role of the Physical Characteristics of the Concentrate

Although bentonite savings is the major economic consideration, a basic decision as to whether or not to go to mullers would also be guided by two characteristics of the materials to be muller: 1) the abrasivity and (2) the filter-cake moisture. Since muller plows are a major cost item, prior to installing a muller, some type of an abrasion test should be carried out on the concentrate to estimate plow wear. As demonstrated by the low maintenance experienced in the plant test program at Cornwall, magnetite concentrate is not a particularly abrasive material. Though not discussed in this paper, filter-cake moisture could also be a major physical limitation. For example, when the filter-cake moisture is too high for balling, excess bentonite has to be added to dry it, and the rheological properties of the mixture may change to the point where mulling is no longer feasible. Thus, since not all material would be equally suitable for mulling ahead of balling, the decision to install mullers in a particular plant would first require evaluation of the abrasivity and filter-cake moisture of the particular concentrate employed.

Conclusion

We have stressed the importance of the physical characteristics of the concentrate as far as the basic applicability of muller mixing is concerned. However, given the several economic considerations we discussed, it will become even more important in future years to find practical methods of making the most efficient use of bentonite. Muller mixing supplies at least one such approach in that it effectively reduces the total bentonite requirement.

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