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LABORATORY INVESTIGATION INTO THE USE OF RED MUD AS A BINDER IN IRON ORE PELLETIZING

by

G.N. BANKS

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SUMMARY

The most commonly used binder in the North American iron ore pelletizing industry is a swelling-type sodium bentonite which is produced in Wyoming, U.S.A. Because this binder has a high silica content and its source is remote from the pelletizing market (especially the Canadian pelletizing market), there has been considerable interest in the development of a suitable replacement. One possible replacement is red mud, which is produced as a by-product in the Canadian aluminium industry. This red mud carries a lower silica content than Wyoming bentonite and is produced in reasonably large quantities in close proximity to the pelletizing market. The present laboratory investigation compares the binding properties of red mud with the binding properties of Wyoming bentonite, when used in iron ore pelletizing. These results indicate that although the red-mud binders do exhibit some binding properties, the green-ball drop number and the oven-dry compressive strengths obtained with red-mud binders are invariably lower than when normal quantities of Wyoming bentonite are used as a binder.

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* Research Scientist, Pyrometallurgy Section, Extraction Metallurgy Division, Mines Branch, Department of Energy, Mines and Resources, Ottawa, Canada.

BACKGROUND

In December, 1966, Mr. B.J. Zubrzycki of the Aluminum Company of Canada Ltd., approached the Mines Branch with the suggestion that "red mud" (a by-product of the aluminum industry) could be useful as a binder in the agglomeration of iron ores. This suggestion was prompted by work performed in Budapest, Hungary (Stahl U. Eisen, 83, 47-49 (1963) No. 1) in which bauxite was mixed with limestone and iron ore to make an ore-cement which they indicate could be used as a binder in iron ore briquetting. Following the discussions with Mr. Zubrzycki, the Mines Branch undertook an investigation into determining the usefulness of red mud as a binder in iron ore pelletizing.

Three types of red mud were made available for this investigation: (1) Arvida (2) "Wet" Jamaica (3) "Dry" Jamaica. The Arvida red mud was available immediately and therefore all preliminary experiments were performed with this material. The Jamaica red muds were received at a later date (July, 1967) and since they contained less silica and had a higher iron content than Arvida mud, it was felt that these muds would probably be more attractive as a binder material. Both of the Jamaica red muds were collected from the tailings pond, but since the "wet" Jamaica mud was from an area covered with liquid while the "dry" Jamaica mud was from an area not covered with liquid, it was suspected that the "wet" mud would more closely represent the material currently produced at the plant. The emphasis in the final pelletizing experiments was therefore placed on the use of the "wet" Jamaica mud as a binder.

EXPERIMENTAL WORK

Raw Materials

The chemical and screen analyses of the materials used in these experiments are reported in Tables 1 to 6. The chemical analyses of the red muds, Beachville lime (excepting CO_2 and L.O.I.), and the size analyses of the Jamaica red muds were performed by the Alcan laboratories. The remaining analyses were performed at the Mines Branch laboratories. Two samples of iron ore concentrate, supplied by Hilton Mines Ltd., were available for these tests. The analyses of these samples are tabulated in Tables 1 and 2. Sample 1 is representative of a coarser shipment received several years ago (1963), while Sample 2 represents the current production at Hilton Mines and was especially procured for this investigation. Two grades of minus 100-mesh hydrated lime were available for use as an additive. The chemical analyses of these limes are reported in Table 3. The chemical and size analyses of the three types of red mud, used as binders, are given in Tables 4 and 5. These size analyses are based on the minus 100-mesh product (approximately 90% of red mud). Because of their rather high tendency to agglomerate, especially in the finer sizes, these screen analyses can only be approximate, but they do indicate the relative fineness of the material. The "wet" Jamaica mud was too difficult to size (even approximately) below 5 microns. The size distribution of the Wyoming bentonite given in Table 6 was obtained from the bentonite used in this investigation, but the chemical analysis was reproduced from the analysis of a Wyoming bentonite given in Mines Branch Monograph 873 (1964).

TABLE 1

Chemical Analyses of Hilton Mines

Iron Ore Concentrates

Constituent	Per Cent	
	Sample 1	Sample 2
Total Fe	69.1	68.8
Fe^{++}	21.4	22.3
Fe^{+++}	47.7	46.5
SiO_2	1.06	1.30
CaO	0.07	0.17
MgO	0.63	1.84
Al_2O_3	0.59	0.72
Total S	0.31	0.50

TABLE 2

Proximate Size Analyses of Hilton

Mines Iron Ore Concentrates

Size (Microns)	% Weight (Cumulative)	
	Sample 1	Sample 2
+149	3.7	1.0
+74	17.1	3.9
+44	31.6	18.4
+25	76.5	51.0
+20	80.8	59.7
+10	93.4	76.9
+5	99.4	-
Density (g/cm^3)	5.071	4.8093
Blaine Surface Area (cm^2/g)	1000	1382

TABLE 3

Chemical Analyses of Hydrated Limes

Constituent	Per Cent	
	Shawinigan	Beachville
CaO	66.7	71.5
MgO	0.1	2.5
SiO_2	1.3	0.4
CO_2	15.2	10.2
C	4.2	-
L.O.I.	31.7	28.2
R_2O_3	-	0.6

TABLE 4

Chemical Analyses of Red Muds

Constituent	Per Cent		
	Arvida	"Dry" Jamaica	"Wet" Jamaica
Fe_2O_3	18.4	49.0	66.6
SiO_2	23.0	2.3	3.2
Al_2O_3	24.7	19.3	18.3
CaO	0.2	2.9	5.7
Na_2O	11.7	5.5	3.0
TiO_2	8.2	1.3	5.6
L.O.I.	8.8	18.2	16.8
CO_2	2.2	-	-
P_2O_5	0.3	-	-

TABLE 5

Proximate Size Analyses of Minus 100-Mesh Red Muds

Size (Microns)	% Weight (Cumulative)		
	Arvida	"Dry" Jamaica	"Wet" Jamaica
+105	-	5.7	1.9
+74	4.1	9.7	3.5
+44	6.8	15.6	6.3
+33	-	18.2	7.2
+20	21.5	22.2	8.9
+15	-	23.9	9.9
+10	36.4	25.9	10.8
+5	57.0	37.5	22.6
+3	74.4	59.1	-
+2	86.7	79.0	-
+1	96.7	95.5	-

TABLE 6

Proximate Size and Chemical Analyses

of a Typical Wyoming Bentonite

Size Analysis		Chemical Analysis	
Size (Microns)	% Wt. (Cum.)	Constituent	Per Cent
+25	1.5	Fe_2O_3	4.2
+10	2.0	SiO_2	59.7
+5	8.8	Al_2O_3	18.2
+4	17.7	CaO	1.5
+3	30.5	Na_2O	2.7
+2	50.2	MgO	2.1
+1	82.7	K_2O	0.5
		SO_3	0.6

Procedure

The evaluation of red mud as a binder in iron pelletizing was to be achieved by comparing its effect with the effect of Wyoming bentonite on the following ball properties:

1. Green-ball drop number.
2. Green-ball compressive strength.
3. Dry-ball compressive strength.

In addition to the above properties, some tests were made on the ability of the green balls to withstand thermal shock as well as the compressive strength of balls which had been fired at indurating temperatures.

The drop strength or drop number of the green balls was determined by dropping 10 balls individually from a height of 18 inches onto a steel plate and then determining the average number of drops required to break the ball. The compressive strength of green balls was determined by testing 10 balls, individually, on an Allis-Chalmer's "Pelletester" machine. This machine measures the diameter of each ball, applies a compressive force (at a uniform loading rate), measures the deformation of the ball as the load is being applied and also the final load when the ball is crushed. This final figure is taken as the compressive strength of the ball. The average strength was determined and then recalculated on the basis of 1/2-inch balls, using the hypothesis that the strength varies as the square of the ball diameter. The dry and fired compressive strengths were both determined on a Dietert sand-core testing machine. In each case the diameter of the ball or pellet was determined on the Pelletester and the average strength for 10 balls or pellets was reported on the basis of 1/2-inch diameter. The procedure used for the thermal-shock and fired-strength tests is described later.

The following general procedure was used to produce balls for testing.

1. Iron ore concentrate was mixed with the desired quantity of binder in a Hobart mixer for 1/2 hour. At least 70% of the desired final moisture content of the green ball was added during this mixing stage.

2. Seed pellets (3 1/2 to 4-mesh size) were made from this mixture in a balling tire. The balling tire consists of an 8 x 20-inch aeroplane tire affixed to a variable-speed drive, which was rotated at 51 rpm for these tests. The finished seed pellets were stored in a humid atmosphere for future use.

3. In each test the mixture was fed at a rate of about 250 g/min. for 4 minutes onto 100g of seed pellets, contained in the balling tire. Sufficient moisture was sprayed into the tire to form balls of the desired final moisture content. The formed balls were allowed to roll for one minute, then removed from the tire and screened to retain the 1/2 to 3/8-inch size. Approximately 90% of the balls were in this size range, the remainder were rejected.

4. Samples of the freshly formed balls were taken for (a) moisture determination (b) green drop-strength (c) green compressive strength (d) oven-dried (110°C) compressive strength (e) air-dried compressive strength (f) thermal-shock tests and fired-compressive-strength tests.

Several different procedures for mixing the red-mud binder and iron ore concentrate were investigated. Some of these procedures were (a) mixing the red mud in the "as received" condition (30% moisture) with the concentrate (b) mixing minus 500-mesh red mud (33% moisture) with the concentrate (c) mixing a 1/1 ratio of dry minus 100-mesh red mud and lime with the concentrate (d) mixing a 1/1 ratio of red mud and lime, firing the mixture at 1250°C for 4 hours, and grinding it to minus 200 mesh to produce an olive-green cement which was then mixed with the concentrate and (e) drying the red mud to a moisture level at which it would flow readily, screening off the plus 100-mesh size, combining the minus 100-mesh size with lime at the desired ratio and then mixing this with the concentrate. The most practical handling scheme appeared to be procedure (e) wherein the Jamaica muds were dried to about 12% moisture and the Arvida mud to about 8% moisture before mixing with the concentrates containing 1% moisture in the case of Sample 1 (coarse concentrates) and 8.6% moisture in the case of Sample 2 (fine concentrates).

RESULTS

Coarse Concentrates

Preliminary experiments, using procedures (a) to (d), indicated that mixtures of red mud, with or without lime, at rates of 100 lb per ton of concentrate gave green-ball compressive strengths in about the same range as obtained with a bentonite binder when added at a rate of 15 lb per ton of concentrate. The compressive strengths of oven-dried balls obtained with the red-mud binders were only about half of those obtained with the bentonite binder, however air-dried 24-hr compressive strengths with red-mud binders (using a 1/1 mud/lime mixture) gave dry-ball strengths equivalent to the oven-dried strengths obtained with the bentonite binder.

The results of several tests, using procedure (e) are outlined in Table 7. The coarser sample of Hilton Iron Ore Concentrate (Sample 1) was used in these tests. Each test listed in this Table and Tables 8 and 9 represents the average of three tests, performed under similar conditions, from the same mixture of binder and concentrate.

The results presented in Table 7 confirmed the results of the preliminary tests, which indicated that red-mud binders would give green compressive strengths in the same order of magnitude as a bentonite binder, and that the compressive strengths of oven-dried balls, using the red-mud binders, would be considerably lower than with the bentonite binder. It should be noted that mixing the binder (red mud and lime) several days before using had no deleterious effect on the strength of the balls subsequently produced.

TABLE 7

Results of Balling Coarse Hilton Iron Ore Concentrate

at Low Moisture Levels

Test No.	Binder		Green Ball			Compressive Strength of Dry Balls (lb)	
	Material	Lb/Ton of Conc**	Moisture Content (%)	Drop No.	Compressive Strength (lb)	Oven-Dried	Air-Dried
1	Nil	-	6.9	2.8	1.8	13.0	9.1
2	Wyoming Bentonite	15	7.0	2.7	2.2	25.0	25.7
3	"	15	6.8	2.8	1.7	24.3	27.1
4	"	7.5	6.7	2.9	1.9	23.3	19.6
5	Shawinigan Lime	20	6.7	3.0	2.5	7.6	16.2
6	"	40	6.8	3.3	2.9	8.2	16.1
7	"	100	7.0	3.6	3.1	10.6	22.8
8	Beachville Lime	20	6.7	2.7	2.4	8.3	19.2
9	"	40	6.6	3.0	3.3	14.9	27.4
10	"	100	6.7	3.9	3.5	17.4	32.5
11	Arvida Red Mud	40	6.8	2.8	2.0	9.4	9.5
12	"	100	7.0	2.8	2.7	9.6	10.4
13	Wet Jamaica Mud	40	6.7	2.4	1.6	12.7	11.8
14	"	100	7.3	2.9	1.9	12.8	13.7
15	Wet Jamaica Mud plus Beachville Lime (1/1 Ratio)	20	6.5	3.0	2.6	6.6	11.2
16	"	40	6.7	2.5	2.6	9.5	17.8
17	"	*40	6.9	3.5	3.8	9.3	18.3
18	"	100	7.1	2.9	2.9	13.8	26.2
19	"	*100	7.1	3.2	3.1	12.8	24.0
20	Wet Jamaica Mud plus Beachville Lime (5/2 Ratio)	20	6.8	2.9	2.5	7.3	9.6
21	"	40	6.8	2.6	2.7	7.5	12.4
22	"	100	7.2	2.8	3.5	12.3	23.0
23	"	*100	7.5	3.0	3.1	10.4	18.2
24	Wet Jamaica Mud plus Beachville Lime (5/1 Ratio)	20	6.7	2.8	2.5	8.1	10.1
25	"	40	7.0	2.6	2.6	7.6	11.1
26	"	100	8.9	3.0	2.3	3.7	5.3
27	"	*100	7.2	3.5	3.1	8.9	17.3
28	Wet Jamaica Mud and Wyoming Bentonite	100 7.5	7.0	3.1	1.6	20.2	20.4

* Red mud and lime mixed several days before use.
** Pounds of binder per 2000 lb of wet concentrate.

None of the balls produced in this series of experiments had drop numbers in the 11-12 range normally obtained on the commercially produced Hilton balls. This was believed to be due to the lower balling moisture content compared to the moisture content (9.3%) normally obtained on the green commercially produced balls. In subsequent experiments the balling moisture level was increased to greater than 8%, although this resulted in balls that were not as uniformly spherical as was the case with the lower moisture level. The results of the series of tests at high moisture levels are given in Table 8.

TABLE 8

Results of Balling Coarse Hilton Iron Ore Concentrate at Higher Moisture Levels

Test No.	Binder		Green Ball			Compressive Strength of Dry Balls (lb)	
	Material	Lb/Ton of Conc*	Moisture Content (%)	Drop No.	Compressive Strength (lb)	Oven-Dried	Air-Dried
29	Nil	-	8.4	5.0	1.4	10.3	8.0
30	Wyoming Bentonite	15	9.1	12.8	3.0	27.7	20.7
31	Wet Jamaica Mud	40	8.3	4.6	2.0	9.6	8.3
32	Dry Jamaica Mud	40	8.7	5.3	1.3	7.7	8.3
33	Arvida Red Mud	40	8.5	4.7	1.6	7.2	6.1
34	Wet Jamaica plus Beachville Lime (1/1 Ratio)	80	9.3	7.0	2.0	5.7	14.7
35	Wet Jamaica Mud and Wyoming Bentonite	7.5 7.5	8.4	6.1	2.6	12.1	11.0
36	Wet Jamaica Mud and Wyoming Bentonite	40 7.5	8.4	6.6	2.6	20.7	15.8
37	Wet Jamaica Mud and Wyoming Bentonite	40 15	9.4	15.6	3.5	30.2	21.9

* Pounds of binder per 2000 lb of wet concentrate.

The higher-moisture green balls gave higher drop numbers, but in some cases this higher moisture had a deleterious effect on the compressive strength of the green and dry balls (compare tests 11 and 33). Only those balls containing at least 15 lb of bentonite per ton of concentrate reached drop numbers in the range of the commercially produced balls.

Fine Concentrates

The compressive strength of oven-dried, commercially produced balls is about 13 lb. In both the high- and low-moisture series, using the coarse concentrate (Sample 1), the compressive strength of dry balls, containing 15 lb of bentonite per ton of concenetrate, was over 20 lb. It was believed that this higher strength was partially due to the difference in screen size of the commercial concentrate and the concentrate being used in this laboratory. The laboratory concentrate had also been stored for several years, which may have affected its mineral surfaces in some manner. A third series of tests was therefore performed with concentrate freshly produced at Hilton Mines (Sample 2). The results of this series of tests are recorded in Table 9. "Wet" Jamaica red mud, Beachville lime hydrate and Wyoming bentonite were the only binders used in this series of experiments.

These results indicate that, in contrast to the results with the coarse concentrate (Sample 1), the compressive strength of dry balls made from fine concentrate (Sample 2) is in about the same order of magnitude as the commercially produced balls. In fact, the moisture content, drop number and compressive strength of green and dry balls recorded in test 44 is almost identical to the results obtained in the commercial production of balls from Hilton concentrates. The slightly lower moisture content of the green balls in test 43 results in a lower drop number and lower compressive strength of green and dry balls, whereas the higher moisture content in test 45 results in a higher drop number, but lower compressive strengths.

The use of "wet" Jamaica mud, alone or in combination with lime does not give overall ball strengths as high as those obtained with bentonite, but the addition of lime to the red-mud binder increased the compressive strength of air-dried balls to about the same order of magnitude as obtained in oven-dried balls, with the use of 15 lb of bentonite per ton of concentrate.

The use of bentonite in combination with "wet" Jamaica mud increases the compressive strength of green and dry balls, but unless 15 lb of bentonite per ton of concentrate is used (test 51), the drop strength of the green balls is lower than that obtained in commercially produced balls (test 44). The use of a mud-lime mixture in combination with 7.5 lb of bentonite per ton of concentrate has little or no effect on the drop strength of the green balls, but does give a slight increase in the compressive strength of the green and dry balls.

Thermal-Shock Treatment

Several tests were made on the ability of the green balls to withstand thermal shock, and the fired compressive strength was determined on those balls which survived this heat treatment. These tests were performed by inserting green balls (within 5 minutes of formation) into a preheated (1300°C) muffle furnace for one hour. The recovery percentage was based on the number of balls (from the original 20 used) which survived the treatment. The results of some of these tests, using the coarse iron ore concentrate (Sample 1), are recorded in Table 10.

TABLE 9

Results of Balling Fine Hilton Iron Cre Concentrate

Test No.	Binder		Green Ball			Compression Strength of Dry Balls (lb)	
	Material	Lb/Ton of Conc*	Moisture Content (%)	Drop No.	Compressive Strength (lb)	Oven-Dried	Air-Dried
38	Nil	-	9.0	6.7	1.7	1.4	1.5
39	"	-	9.7	6.9	1.4	1.8	1.5
40	Wyoming Bentonite	6	8.8	7.1	2.3	5.4	4.7
41	"	7.5	8.8	7.0	2.4	6.9	5.4
42	"	10	8.6	7.1	2.9	7.2	6.2
43	"	15	9.2	11.8	3.0	12.2	11.4
44	"	15	9.3	12.4	3.5	13.2	12.4
45	"	15	10.3	22.5	2.4	11.6	10.4
46	Wet Jamaica Mud	20	8.3	4.8	2.3	2.9	2.9
47	"	40	8.6	6.2	2.2	4.3	4.8
48	"	100	8.7	5.5	2.3	6.1	6.9
49	Wet Jamaica Mud and Wyoming Bentonite	40 7.5	9.0	6.2	3.2	12.2	12.3
50	"	40 10	9.5	9.7	3.4	13.3	13.6
51	"	40 15	9.5	13.0	3.8	17.6	15.3
52	"	7.5 7.5	9.1	6.1	2.6	8.4	7.6
53	Wet Jamaica Mud plus Beachville Lime (1/1 Ratio)	40	8.3	4.1	2.5	7.7	13.4
54	"	100	8.9	4.3	2.5	9.5	18.0
55	Mud-Lime Mixture (1/1 Ratio) and Wyoming Bentonite	7.5 7.5	9.3	6.5	2.7	7.9	8.7
56	"	40 7.5	8.8	7.0	2.9	10.4	17.7

* Pounds of binder per 2000 lb of wet concentrate.

TABLE 10

Compressive Strength and Recovery After Thermal-Shock Treatment

Group	Test No.	Binder	Compressive Strength (lb)	Recovery (%)
A	1	Nil	390	100
	2	Bentonite	327	100
	12	Arvida Red Mud	606	100
	14	Wet Jamaica Red Mud	275	100
	28	Red Mud and Bentonite	310	100
	30	Bentonite	263	95
	33	Arvida Red Mud	374	100
B	7	Shawinigan Lime	230	5
	8	Beachville Lime	310	50
	10	Beachville Lime	-	0
	18	Mud-Lime Mixture	322	20
	19	Mud-Lime Mixture	361	25
	22	Mud-Lime Mixture	397	55
	23	Mud-Lime Mixture	502	35
	27	Mud-Lime Mixture	571	50
	34	Mud-Lime Mixture	338	40

This series of tests has been divided into two groups, the first in which no lime was present in the binder (group A) and the second in which lime was present (group B). It is obvious that the percentage of pellets that survived the heat treatment was much higher in group A than in group B. Many of the balls in group B disintegrated with explosive violence when heated rapidly to 1300°C and the maximum survival of pellets in any test did not exceed 55%. On the other hand, balls made without any lime binder and using bentonite, red mud or no binder (group A) withstood this severe heat treatment, with a survival rate greater than 95%. However, when similar thermal-shock tests were performed on green balls made from the finer concentrate (Sample 2), the balls, regardless of what type of binder was used, disintegrated immediately. This is believed to have been due to the fact that the balls made from the finer concentrate would have a much lower porosity than those made from the coarser concentrate, and the diffusion rate of moisture within the low-porosity balls would be much lower than in the balls of higher porosity. Under the influence of the extremely rapid heating, the moisture in the low-porosity balls probably turned to steam before it had time to diffuse out to the surface, thus causing the disintegration. In the case of the group B tests, the carbon dioxide added through the lime addition, probably causes an increase in the gas volume which is too high to be handled, even by the higher-porosity balls.

The compressive strengths of the fired pellets, as listed in Table 10, appeared to be erratic and unrelated to the particular binder used.

However, it may be of some significance to note that with the exception of the Shawinigan lime (Test 7) all of the binders gave fired strengths at least as high as were obtained with bentonite in Test 30 (263 lb), and most were as high as obtained with bentonite in Test 2 (327 lb).

Other Experiments

In addition to the above experiments, several experiments were performed on various methods of curing the green balls, containing a mud-lime binder, in an attempt to increase the compressive strengths of dry balls. Some of these methods were (a) placing green balls in a humid atmosphere for periods up to 48 hours (b) exposing green balls to wet or dry CO_2 atmosphere for periods up to 30 minutes (c) placing green balls in a preheated oven at temperatures of 200°C, 500°C, or 900°C for periods up to 10 minutes.

Compressive strengths as high as 60 lb were obtained on dry balls, containing a mud-lime binder (1/1 ratio) at 100 lb/ton of concentrate, when they were placed in a humid atmosphere for 24 hours and then air-dried for 24 hours. The use of a CO_2 atmosphere gave maximum compressive strengths of dry balls in about the same order of magnitude as air drying for 24 hours. Rapid drying of green balls did not effectively increase compressive strength until oven temperatures were raised to 900°C.

DISCUSSION

The high iron and low silica contents of red muds, especially those of the "wet" Jamaica mud, make them attractive substitute binders from the chemical point of view for the high-silica low-iron Wyoming bentonite, which is the most commonly used binder in the North American iron ore pelletizing industry. Silica is the major impurity in practically all iron ores, and because great progress has been made in recent years in reducing it to low levels in the concentrating stage, producers are reluctant to add any more silica than is necessary in the pelletizing stage. Fifteen lb of bentonite per ton of concentrate (the typical addition) increases the silica content of the pellets by about 0.45%, whereas 100 lbs of "wet" Jamaica red mud per ton of concentrate would increase the silica content by only about 0.15%. Furthermore the high iron contents of the red muds can be considered as an additional asset.

The laboratory experiments, performed in this investigation, indicate that the use of red mud as a binder does not give as strong a green or dry ball as obtained when Wyoming bentonite is used as a binder. There are even indications that the drop strength or drop number is higher with no binder than when red mud is used as a binder. However, in spite of these rather negative results, it is possible that with some other concentrate and a gentler ball-handling procedure within the pelletizing plant, the chemical composition and the lower cost of red mud may be an over-riding factor. In any event the compressive strength of fired pellets (with red mud being used as a binder) appears to be comparable to that obtained with the use of a bentonite binder. In order to ascertain the ultimate strength of fired pellets a more realistic firing schedule should be employed and the strength of the fired pellets should be compared on the basis of tumble tests and Linder tests. These strength tests would require a much greater quantity of pellets than was produced in the reported laboratory tests.

CONCLUSIONS

Red mud or a mixture of red mud and lime exhibits some binding properties in pelletizing Hilton Mines iron ore concentrate, but the green-ball drop number and the oven-dry compressive strength of balls made with the use of a red-mud binder are invariably lower than when normal quantities of Wyoming bentonite are used as a binder. The compressive strength of fired pellets appears to be independent of the binder used, but when lime is used in the binder, or when the iron ore concentrate is more finely ground, the green balls are more subject to thermal shock.