FELDSPAR TAILINGS UTILIZATION

FINAL REPORT

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INTERNATIONAL MINERALS
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Spruce Pine, North Carolina

THE FELDSPAR CORPORATION
Spruce Pine, North Carolina

LAWSON-UNITED FELDSPAR
AND MINERAL COMPANY
Spruce Pine, North Carolina

NORTH CAROLINA STATE UNIVERSITY
Raleigh, North Carolina

Research Conducted by

Minerals Research Laboratory (Asheville, N. C.)
Department of Civil Engineering
Department of Engineering Research

SCHOOL OF ENGINEERING
NORTH CAROLINA STATE UNIVERSITY
Raleigh, North Carolina

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PROJECT SUMMARY

During 1968 and 1969, a feldspar tailings utilization project was sponsored by the U. S. Bureau of Mines, North Carolina State University, and three feldspar companies in the Spruce Pine, North Carolina area. The objectives of the project were to define the feldspar tailings problems at the three feldspar plants and to find solutions to the expensive disposal problems. An Advisory Committee, which guided the project, was formed in June 1968, and it consisted of a representative from each feldspar company, one from the Minerals Research Laboratory in Asheville, and one from the Department of Engineering Research of North Carolina State University at Raleigh. The three phases of the project were: (1) sampling and characterization of the tailings, (2) search for uses for the tailings as they are produced or with minimum processing (only drying, grinding, and sizing), and (3) research to find uses for the feldspar tailings in manufactured products. The project was planned as a three year project, and the first phases were to be conducted in the Minerals Research Laboratory. The end product and market research was to be conducted at the North Carolina State University at Raleigh.

The major part of the first year was devoted to determining quantities and qualities of the different tailings streams. The first phase of the project revealed very high tonnages of recoverable feldspar in the tailings of all three feldspar plants and ways to recover the feldspar. The three companies decided to concentrate their efforts on feldspar recovery either by reclamation from the tailings as suggested by the Minerals Research Laboratory or by improvements in the existing plants. Since amounts and quality of the tailings would be changed in the coarse of plant improvements, the tailings project was discontinued after one year duration. Before the research was terminated, preliminary work was accomplished in evaluating feldspar tailings for use in construction projects, for use in calcium-silicate building products, and for use in the production of glass and bricks.

Progress reports on the different phases of the project are summarized below:

Report No. 1 - Preliminary Feldspar Tailings Evaluation by Immo H. Redeker

During the planning time for the tailings project, random samples were taken at the three feldspar plants to define sampling procedures and to determine the best sample evaluation procedures.

Report No. 2 - Feldspar Tailings Evaluation by Robert D. Kauffman

Samples were taken of the five tailings streams at the three plants on a day to day basis on ten successive working days, and on a week to week basis for ten weeks. Sampling procedures and test work on the samples together with data on amounts of tailings and feldspar that could be reclaimed from the tailings are presented together with a statistical analysis of the variations from day to day and from week to week.

Report No. 3 - Recovery of By-Products from Feldspar Plant Tailings by Immo H. Redeker

This report gives a summary of the project at the end of the first nine months. A description of the feldspar industry in the Spruce Pine area is followed by the results of the tailings evaluation. Out of 250,000 tons per year of tailings material disposed of now, about 85,000-100,000 tons of feldspar can be recovered. The cost of reprocessing the tailings was estimated to be $5.00

per ton of feldspar recovered. Process research for a most economical flowsheet for recovery of feldspar and quartz and possibly mica in a pilot plant at the Minerals Research Laboratory was recommended. The high grade quartz from reprocessing apparently would make excellent raw material for sand-lime bricks and foamed calcium-silicate building products. With representative samples available from the sampling program, end product research was started at the Engineering Research Department and Civil Engineering Department of North Carolina State University.

Report No. 4 - Beneficiation of Filter Cake Tailings by J. Philip Neal

A reliable feed-preparation and flotation procedure was developed for tailings filter cake. This material is finer than any previously treated by flotation for the recovery of feldspar and quartz. Up to 40 percent of the fine filter cake could be recovered as feldspar which is fine enough for use in ceramic whiteware production.

Report No. 5 - Evaluation of Feldspar Tailings by Flotation by Edwin H. Bentzen III

Some coarse tailings material had presented flotation difficulties when using standard procedures, and this part of the research was directed toward finding a solution to this problem. A flotation procedure that could remove mica and iron minerals simultaneously from the tailings was tested and found to be useful.

Final Report

Part I. Drying and Fine Grinding of Feldspar Tailings by Edwin H. Bentzen III

Tonnage quantities of different feldspar tailings streams were dried and ground in a three foot by six foot, Porox-lined, air-swept, pebble mill. This material was prepared for use in the evaluation of feldspar tailings for use in construction and in production of calcium-silicate building materials and glass and bricks.

Part II. Use of Feldspar Tailings in Calcium-Silicate Building Materials by Immo H. Redeker

Laboratory tests showed that sand-lime bricks meeting ASTM-SW strength requirements could be made from Spruce Pine tailings in spite of high feldspar contents. Weathering tests for efflorescence should be made before final conclusions can be drawn. Laboratory tests produced interesting samples of lightweight, foamed, calcium-silicate building material.

Part III. Evaluation of Feldspar Tailings for Brick and Glass Production by Billy M. Gay, Arthur E. Lucier, Robert F. Stoops

Only glasses of very low commercial value can be produced from the unprocessed tailings. Some tailings could be used as brick raw materials; however, the process variables such as kiln atmosphere and kiln temperature gradients would have to be controlled very carefully. With additional research bricks probably could be produced commercially from feldspar tailings.

Part IV. Feldspar Tailings Utilization for Construction Purposes by Grigg Mullen

The coarse tailings sands can be used as cement mortar sands; however, water and cement requirements make this material a marginal competitor with natural sands. The coarse tailing sands can be used to make sand asphalts of acceptable strength and stability with near normal amounts of cement. This application deserves development. The fine tailings can be stabilized with Portland cements or a mixture of Portland cement, lime and flyash. The fine tailings so stabilized could be used as foundation layers for structures and for low cost roads. The use in combination with flyash, another waste product of industry, is of special interest; and comprehensive studies to develop specific guidelines for this application are warranted.

Part I

Drying and Fine Grinding of Feldspar Tailings

by
Edwin H. Bentzen, III

INTRODUCTION

In the Tailings Project Advisory Committee meeting held January 28, 1969, in Asheville, it was decided that the Laboratory would discontinue the investigation of mineral beneficiation. Instead, the investigators would concentrate their efforts toward end product use of the tailings "as is". This report contains the data associated with producing a fine ground product to be used later in product development.

PROCEDURE

The samples used in this work are identified as follows:

No. 3425 - Five tons of wet material from Lawson's upper pond scraper pile.

No. 3432 - Two tons of wet filter cake material from I. M. C. tailings plant.

No. 3433 - Three tons of wet coarse fraction from I. M. C. tailings plant.

All material was shipped by truck and arrived in a drained condition. Samples were taken from each load for moisture determination and screen analyses. The results are shown in Table I.

Before subjecting any of the samples to processing, a 500 pound reference sample was taken. This material was placed in a 55 gallon enamel-lined drum and sealed to prevent loss of moisture. The remainder of each of the tailings samples was then dried in an oil-fired drier which was two feet in diameter and thirteen feet long. During each test run, moisture samples were taken from the feed. In order to acquire cost data, the rate of oil consumption was also measured.

Lawson's tailings were dried using direct firing; but it became apparent that this resulted in large dust losses. Therefore, it was decided that the remaining two samples would be run using indirect firing. This increased the cost, but resulted in considerable reduction in the loss of fine material. Data obtained from this work are shown in Table II. The following cost data are based on information offered by the local oil supplier: No. 2 fuel oil - 136,000 BTU per gallon, 7.206 pounds per gallon, 12 cents per gallon.

The dried material was placed in steel drums and the lids were fastened securely. Three 55 gallon drums of each material were then set aside for later reference. In the case of I. M. C. filter cake material, about one-half ton was dried in pans in an oven. Five hundred pounds of this material was also saved for reference. The remainder of each tailing sample was then used as feed to a pebble mill.

The Porax-lined, air-swept, pebble mill used for fine grinding the dried tailings was three feet in diameter and six feet long and had a closed-circuit air classification system. The pebble load was 1,100 pounds, consisting of 300 pounds of two inch porcelain pebbles and 800 pounds of one inch pebbles.

Feed rates varied due to bridging in the feed hopper. Samples for determining production and circulating load rates were taken every half hour, and screen analyses were run on each for control information. The products were collected in 55 gallon drums which were sealed to prevent contamination. Generalized information on the products is shown in Figures 1 and 2.

Ten pound samples were cut out of each tailing material, each of the dried but unground samples, and each of the ground products. These samples will be kept on hand, along with the bulk of the ground material, for future shipment to other evaluators.

After completion of the grinding, tests were conducted to determine the physical and chemical characteristics of the materials. The determinations made were size analysis, bulk weight, pH, and color. These data are shown in Tables III through V. Color was determined with a Photovolt reflection meter using blue, green, and amber filters. MgO was used as a color standard, and reflection readings from the MgO with the above filters were assigned values of 100 each.

RESULTS AND DISCUSSION

The screen analyses in Table I were compared with results obtained previously, and the particle sizes of the samples evaluated were representative of those of the tailings streams from which they were obtained.

The results obtained are shown in Figures 1 and 2 and in Tables II through V. In examining the data shown in Table II, the following information should be considered: tests 1 through 6 on Lawson tailings were performed using direct contact of flame and material. This resulted in better heat transfer and lower drying costs. I. M. C. coarse and filter cake samples were dried using indirect heating; hence drying costs were slightly higher. The first tests on each type of material can not be considered representative, because various adjustments were required for each sample. The material identified as "excess" is that material left in the drier after each days tests and that remaining after completion of the tests. It is shown only to relate to the total amount of material dried.

The drying costs shown do not include labor. However, when the small size and inefficiency of the drier used are taken into account, it is expected that a properly designed and operated drier could do the same job in production for half the drying costs shown.

Figures 1 and 2 are graphs resulting from the collection of data every half-hour during the fine-grinding experiments. Figure 1 pertains to Lawson tailings and shows the relationship between production rate in pounds per hour and fineness production rate in percent minus 325 mesh. Each days run divided into half-hour segments is shown as the abscissa. In the last days of the tests, an effort was made to increase the grinding rate, but apparently the capacity of the mill to produce this fine material had already been reached. The degree of fineness of product went down with increased production rate.

Data on I. M. C. tailings are shown in Figure 2. Referencing of data is the same as in Figure 1. Production rates were slightly higher for the I. M. C. coarse than for Lawson's tailings, but the product was coarser. It was thought that the fine size of the Lawson filter cake would allow a very high feed rate; however, it was found that the fineness sought could be produced only at relatively low feed rates.

It should be emphasized that the object of this work was to produce the fine-ground materials. With the limited amount of material on hand, the many operating variables could not be studied.

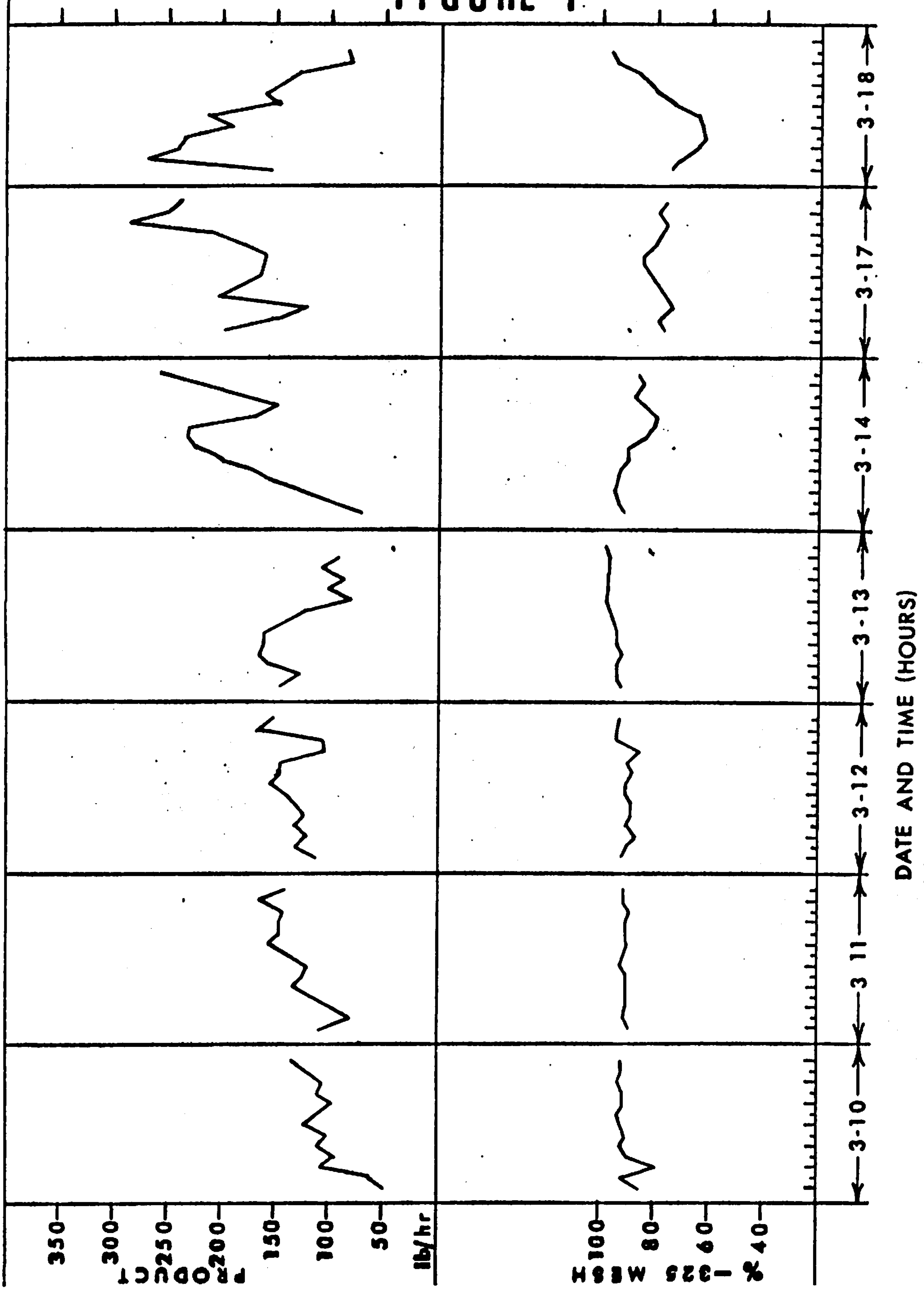
Material from Feldspar Corporation was not included in this work because, according to company officials, the tailings flotation plant now under construction will change the characteristics of the tailings.

CONCLUSIONS

1. The material used for this work was representative of the material produced by the plants at that time.

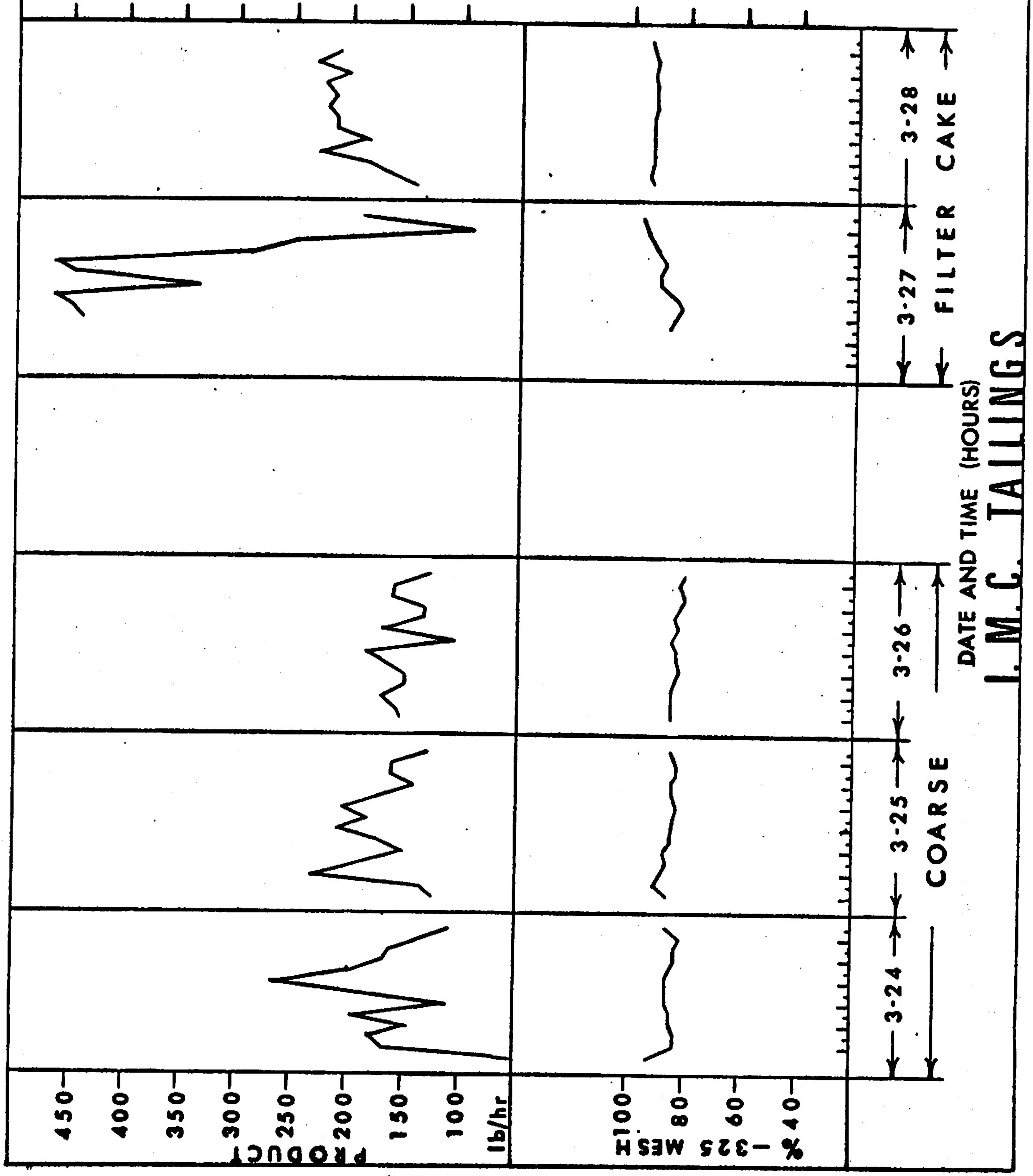
2. Samples of the fine ground feldspar plant tailings were prepared for future test work.

FIGURE 1



LAWSON TAILINGS

FIGURE 2



PRODUCT
lb/hr
450
400
350
300
250
200
150
100
% -325 MESH
100
80
60
40
3-24
3-25
3-26
3-27
3-28
COARSE
FILTER CAKE
DATE AND TIME (HOURS)
I.M.C. TAILINGS

TABLE I
SCREEN ANALYSES AND MOISTURE CONTENTS
OF TAILINGS SAMPLES AS-RECEIVED

Screen Size (Tyler)	Number 3425 (Lawson)		Number 3433 (I.M.C. Coarse)		Number 3432 (I.M.C. Filter Cake)	
	Wt %	Cum %	Wt %	Cum %	Wt %	Cum %
+20	2.4	2.4	1.0	1.0	-	-
-20+28	2.8	5.2	12.2	13.2	0.1	0.1
-28+35	8.0	13.2	19.1	32.3	0.1	0.2
-35+48	10.0	23.2	18.1	50.4	0.4	0.6
-48+65	11.6	34.8	14.6	65.0	0.5	0.1
-65+100	12.0	46.8	12.0	77.0	1.1	2.2
-100+150	11.9	58.7	8.4	85.4	2.4	4.6
-150+200	11.0	69.7	6.1	91.5	6.0	10.6
-200+270	7.2	76.9	3.0	94.5	9.8	20.4
-270+325	6.7	83.6	2.0	96.5	12.6	33.0
-325+400	2.8	86.4	0.7	97.2	6.4	39.4
-400	13.7	100.1	1.8	100.0	60.7	100.1
Moisture	16.5%		8.0%		20.8%	

TABLE II
COST DATA ON DRYING OF FELDSPAR TAILINGS

Sample Description	Feed Rate of Material lb/hr Dry	lb/hr Wet	Percent Moist. in Sample	Pounds of Water Per Ton	Per Ton Oil Consumption lbs	gals	1,000 BTU per lb H_2O	Cost $/Ton of Dry Material
Lawson Tailing								
Test #1 (Start up)	582	752	-	-	-	-	-	-
#2	598	697	14.2	284	44	6.12	2.93	0.86
#3	664	760	12.3	246	40	5.56	3.07	0.76
#4	569	661	13.8	276	38	5.28	2.60	0.73
#5	658	764	13.9	278	41	5.70	2.79	0.79
#6	642	744	13.7	274	-	-	-	-
I. M. C. Coarse								
Test #1 (Start up)	379	426	11.1		15.4	2.24	6.20	1.42
#2	493	539	8.6	46	15.0	2.08	6.15	1.01
#3	669	748	10.6	79	14.8	2.06	3.54	0.74
#4	558	620	9.9	62	14.6	2.03	4.45	0.87
#5	650	725	10.4	75	15.1	2.10	3.82	0.78
#6	587	641	8.4	54	14.4	2.00	5.04	0.82
#7	600	645	7.0	45	14.6	2.03	6.14	0.81
#8	625	681	8.2	56	14.4	2.00	4.86	0.77
Excess material	933	-	-	-	-	-	-	-
I. M. C. Filter Cake								
Oven dried	1,047	1,248	16.1	201	-	-	-	-
Test #1 (Start up)	283	335	15.5	52	15.6	2.17	5.67	1.84
#2 (Start up)	248	296	16.2	48	15.1	2.10	5.95	2.04
#3	404	485	16.8	81	15.2	2.11	3.54	1.25
#4	413	495	16.6	82	15.3	2.12	3.52	1.23
#5	394	468	15.9	74	14.4	2.00	3.68	1.22
#6	420	502	16.4	82	15.0	2.08	3.45	1.19
#7	404	485	16.7	81	15.1	2.10	3.52	1.25
#8	397	469	15.4	72	15.1	2.10	3.97	1.27
#9	408	492	17.0	84	15.2	2.11	3.42	1.24
#10	382	446	14.2	64	15.0	2.08	4.42	1.31
Excess material	285	-	-	-	-	-	-	-

TABLE III
PROPERTIES OF LAWSON-UNITED FELDSPAR
AND MINERAL COMPANY GROUND TAILINGS

Particle Size Analysis (Tyler Mesh)

Screen Size	Percent
-270+325	6.4
-325	93.4

Dry Bulk Weight - 37.3 lb/cu ft

Color (Dry)	
Blue	76
Green	79
Amber	81

pH Values	
After 1 hour	9.0
1 day	9.0
1 week	8.5

TABLE IV
PROPERTIES OF INTERNATIONAL MINERALS AND CHEMICAL COMPANY GROUND COARSE TAILINGS

Particle Size Analysis (Tyler Mesh)

Screen Size	Percent
-270+325	28.8
-325	71.2

Dry Bulk Weight - 43.8 lb/cu ft

Color (Dry)

Blue	81
Green	82
Amber	84

pH Values

After 1 hour	9.1
1 day	8.9
1 week	8.9

TABLE V
PROPERTIES OF INTERNATIONAL MINERALS AND CHEMICAL COMPANY GROUND FILTER CAKE

Particle Size Analysis (Tyler Mesh)

Screen Size	Percent
-270+325	9.2
-325	90.8

Dry Bulk Weight - 31.9 lb/cu ft

Color (Dry)

Blue	66
Green	71
Amber	73

pH Values

After 1 hour	8.8
1 day	8.8
1 week	8.5

Part II

Use of Feldspar Tailings in Calcium-Silicate Building Materials

by

Immo H. Redeker

INTRODUCTION

Calcium-silicate bonded building products consist of highly silicious sand material bonded together with hydrated calcium silicates. It was originally proposed for the feldspar tailings project that calcium-silicate building material be made only from the high quartz products from reprocessing of tailings, because it is reported in the literature and by other investigators that feldspar in the sand has a detrimental effect on the sand lime brick quality. Reportedly, the reaction between lime and feldspar releases soluble Na and K-salts and causes efflorescence and lowers the strength of the bricks. Since high quartz sand from tailings reprocessing was not available, a few test series were run to find out what quality of products could be made from unprocessed tailings with high feldspar content when used as they are, or after grinding, or when used as mixtures of ground and unground material.

Two different calcium-silicate products were investigated; pressed sand-lime bricks, and foamed lightweight building block or panel material. The tailings materials used were Lawson United Feldspar and Mineral Company tailings, and coarse tailings and fine filter cake from International Minerals and Chemical Corporation's feldspar mine at Spruce Pine, North Carolina. Tailings from Feldspar Corporation were not tested because this company is in the process of installing facilities to reprocess their tailings for feldspar and quartz recovery as recommended in Feldspar Tailings Report No. 3. Silica from Feldspar Corporation's reprocessing plant should be a good calcium-silicate raw material and should be tested later when available. The pertinent data for tailings and lime samples used are presented in Tables I and II.

Sand-Lime Bricks

Sand-lime brick manufacturing is not new, but the technical aspects of consistent economic production have been solved only in recent years in Europe where sand-lime bricks are very popular. Sand-lime bricks can be made with high compressive strength (A.S.T.M. requires 4,500 psi average of 5 bricks for grade SW), low adsorption, with high resistance to freezing and thawing and in colors of natural silver gray or pastel shades. The bricks can be split for a textured surface. They retain their exact dimensions during autoclave curing which makes complete automation of the brick-making process possible. The bricks can be shipped immediately after removal from the pressure vessel. Figure 1 shows a schematic flowsheet of a sand-lime brick plant.

Sand-lime bricks are manufactured by mixing quicklime or hydrated lime and high-silica sand in a ratio of 85 to 95 percent sand to 15 to 5 percent lime and adjusting moisture for good hydration and for easy pressing and forming. The moist sand lime mixture is pressed at 4,000 to 8,000 psi and steam cured in autoclaves at pressures of up to 275 psi for a period of four to five hours. Hydrated calcium silicates form at these temperatures and pressures in the steam atmosphere through the reaction of the quartz with the lime. The hydrated calcium silicates, mainly monocalcium silicate hydrate, called tobermorit, is the same binding agent as is found in Portland cements. In the case of concrete the Portland cement is the bonding agent and the aggregate is only a filler, but in the case of sand-lime bricks the quartz aggregate reacts with the lime, and particle to particle cementation occurs by formation of tobermorit. Table III gives the general reactions that take place in reactor and autoclave.

Foamed Lightweight Building Materials

The foamed calcium-silicate industry is highly developed in Sweden and Germany, and it is rapidly expanding in Europe. Foamed lightweight building materials are manufactured by mixing fine silicious sands with quicklime or hydrated lime and water. The mixture is intensively mixed and aluminum powder is added. The aluminum reacts with the water to form hydrogen bubbles in the mixture. The material is poured into forms, where the formation of the hydrogen bubbles causes it to expand. After the material solidifies, the forms are removed, and the final hardening process is accomplished in autoclaves in the same way that sand-lime bricks are hardened. The most important properties of lightweight calcium-silicate building products are high strength and low weight. They offer the possibility of manufacturing fairly large building elements that can be sawed, nailed, drilled, tongue-and-grooved similar to wood, but they have the advantage of resistance to weather, decay, and termites.

PROCEDURE

Sand-Lime Bricks

Batches containing tailings materials, quicklime or hydrated lime and water as shown in Table IV were mixed thoroughly by hand in plastic bags and stored overnight before pressing. Twenty bricks were pressed at either 6,000 or 8,000 psi in a one by two inch stainless steel die on the Carver laboratory press, and they were autoclaved for four hours at 275 psi saturated steam in a Cenco A.S.T.M. autoclave. The main variables in the test series were the lime-sand ratio, different tailings samples as received, mixtures of tailings sand as received and ground, and the forming pressure (either 6,000 or 8,000 psi).

Cold water absorption (24 hour soak) and boiling water absorption (5 hour boil) were determined by "Standard Method of Sampling and Testing Brick," ASTM C67-60. Ten bricks of each sample were crushed in the Carver laboratory press to determine compressive strengths.

Foamed Lightweight Building Materials from Feldspar Tailings

In a short test series, a few samples of lightweight foamed calcium-silicate were made using Lawson United Feldspar Company's tailings, ground and unground, quicklime or hydrated lime, aluminum, and small amounts of white Portland cement to accelerate initial setting in the forms, Table V. Quite a few mixing tests had to be conducted to obtain the desired low bulk weights of less than 62.4 lb/cu ft.

DISCUSSION

Sand-Lime Bricks

The test results are reported in Table IV. Most bricks made meet the required A.S.T.M. compressive strength of SW bricks of 4,500 psi. There are no A.S.T.M. standards for adsorption of sand-lime bricks; and, when testing very small test bricks as was done because of equipment limitations, high absorption values are usually obtained. The absorption values obtained and reported are probably higher than those to be expected with standard-size bricks. It was suspected that soluble Na and K-salts would be released by the reaction of lime and feldspar and that the salts would show in weatherexposed bricks as efflorescence. Chemical analysis of boiling water-leached brick material showed only very small amounts of soluble Na_2O and K_2O in the water (a maximum of 0.33 percent Na_2O and 0.10 percent K_2O). Efflorescence tests, freeze-and-thaw tests, and atmospheric weathering tests should be made to determine the suitability of these bricks for use in North Carolina. Literature research and correspondence with knowledgeable people in the sand-lime brick field may shed more light on this problem. Since production of sand-lime bricks appears promising, the following plant and production cost estimates are given.

Capital and Operating Cost for a Sand-Lime Brick Plant

Capital Cost - Two-press plant producing 30 million bricks per year during a two shift operation. $900,000

Material Requirements and Other Cost per 1,000 Bricks

Tailings from Spruce Pine, 2.5 tons @ $1	$2.50
Lime from Knoxville, 600 lbs. @ $18/ton	5.40
Fuel, 1.6 million B.T.U.	1.60
Lights and Power, 20 kw hours	0.20
Total labor and maintenance, 2 man hours	5.00
Mold cost	1.25
Depreciation, 10 yrs. @ 30 million bricks/yr.	3.00
Total cost per 1,000 bricks	$18.95

A plant site of at least two acres and a total power supply of at least 200 HP is required.

Foamed Lightweight Building Materials from Feldspar Tailings

Blocks of good strength and appearance were obtained with 58 lb/cu ft density. The blocks were cured in the Cenco laboratory autoclave in steam atmosphere for four hours at 275 psi. The compressive strength could not be determined but should be around 500-1000 psi, which would be sufficient for wall partitions and nonstructural building requirements. Table V presents the results of test work at the laboratory. Because of early termination of the feldspar tailings project, only a very few tests have been conducted.

CONCLUSIONS

Laboratory test work showed that sand-lime bricks meeting A.S.T.M. SW strength requirements could be made from Spruce Pine tailings in spite of the high feldspar content. Tests for efflorescence should be made before final conclusions are drawn, it is also advisable to run absorption tests on full-size bricks.

Laboratory test work produced interesting samples of lightweight, foamed, calcium-silicate building material. More laboratory test work is needed to gain information about best manufacturing conditions.

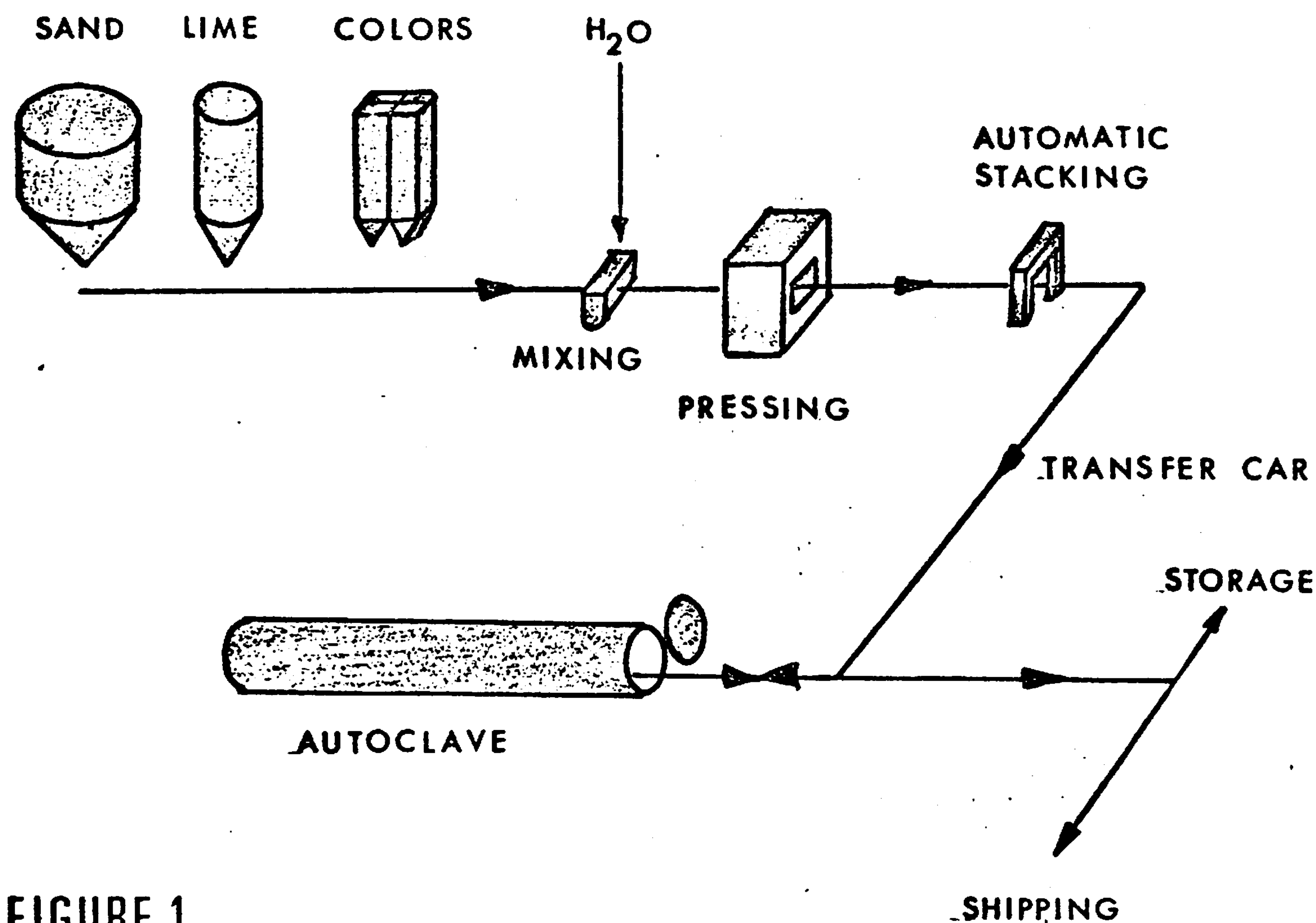


FIGURE 1
SAND LIME BRICK PLANT
SCHEMATIC

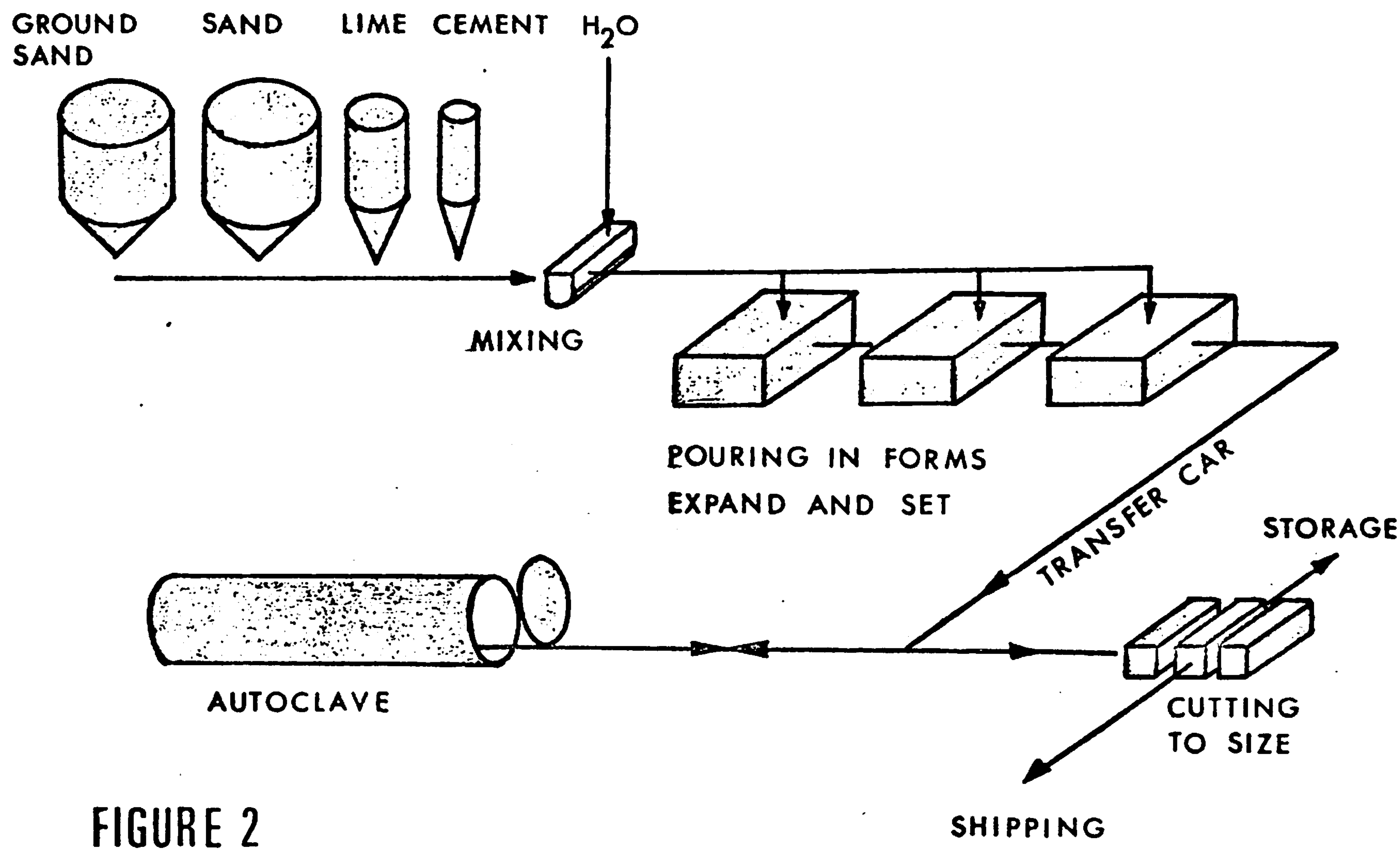


FIGURE 2
FOAMED CALCIUM-SILICATE PLANT SCHEMATIC

Table I

Screen Analyses and Chemical and Mineralogical Compositions of Feldspar Tailings Used

	Lawson-United		International Minerals Company			
	LT Tailings As Received	LT-200 Tailings Ground to -200 Mesh	IMC-C Coarse Tailings	IMC-C-200 Coarse T. Ground to -200 Mesh	IMC-FC Filter Cake As Received	IMC-FC-200 Filter Cake Ground to -200 Mesh
Size Analysis - Tyler Mesh:						
+20	2.4	-	1.0	-	-	-
-20+28	2.8	-	12.2	-	0.2	-
-28+35	8.0	-	19.1	-	0.1	-
-35+48	10.0	-	18.1	-	0.4	-
-48+65	11.6	-	14.6	-	0.5	-
-65+100	12.0	-	12.0	-	1.1	-
-100+150	11.9	-	8.4	-	2.4	-
-150+200	11.0	-	6.1	-	6.0	-
-200+270	7.2	-	3.0	-	9.8	-
-270+325	6.7	6.4	2.0	28.8	12.6	9.2
-325+400	2.8	93.6	0.7	71.2	6.4	90.8
-400	13.7	-	1.8	-	59.0	-
Chemical Analysis:						
% K_2O	2.90	x*	2.70	x	4.20	x
% Na_2O	3.68	x	2.89	x	4.00	x
% CaO	1.02	x	0.72	x	1.17	x
% MgO	-	-	-	-	-	-
% Fe_2O_3	0.60	x	0.66	x	0.93	x
% SiO_2	77.8	x	81.0	x	69.3	x
% Al_2O_3	13.5	x	11.0	x	18.6	x
% Ign. Loss	0.54	x	0.40	x	1.63	x
Approximate Mineral Composition						
Potash Spar	13	x	11	x	19	x
Soda Spar	31	x	23	x	33	x
Lime Spar	4	x	3	x	6	x
Muscovite	6	x	5	x	7	x
Clay	4	x	2	x	8	x
Quartz	43	x	56	x	28	x

*x = Same as unground

TABLE II

SCREEN ANALYSES AND CHEMICAL COMPOSITIONS OF LIME PRODUCTS

	Quicklime (Williams, Knoxville)	Hydrated Lime (Foote, Knoxville)
Size Analysis - Tyler Mesh:		
Passing 200 mesh	98%	99.5
Passing 325 mesh	-	95.9
Chemical Analysis:		
% CaO	96.4	74.6
% MgO	0.6	0.5
% SiO_2	0.3	0.2
% Fe_2O_3	0.2	0.1
% Al_2O_3	0.4	0.3
% Ign. Loss	1.7	24.3

TABLE III

SANDLIME REACTION

1 Hydrating of Raw Material:

$$\underset{\text{Quicklime}}{CaO} + \underset{\text{Sand}}{SiO_2} + \underset{\text{Water}}{H_2O} \longrightarrow \underset{\text{Hydrate}}{Ca(OH)_2} + \underset{\text{Sand}}{SiO_2} + \text{Heat}$$

2. Pressing (4,000-8,000 psi)

3. Hardening in Steam Pressure Vessel:

$$\underset{\text{Hydrate}}{Ca(OH)_2} + \underset{\text{Sand}}{SiO_2} + \underset{\text{Water}}{H_2O} \xrightarrow{\text{4-8 hrs. at 150-175 psi}} \underset{\text{Monocalcium}}{(CaO)x} \ \underset{\text{Hydrate}}{(SiO_2)y} \ \underset{\text{Silicate}}{(H_2O)z}$$

TABLE IV

SAND-LIME BRICK COMPOSITIONS AND PROPERTIES

Composition: Material*	Composition: Grams	Pressing Pressure psi	Compressive Strength psi	Absorption: Cold %	Absorption: Boiling %	Apparent Specific Gravity	Remarks
LT	425						
LT-200	425						
CaO	150						
Water	100	6,000	6,100	16.6	16.6	1.80	
LT	425						
LT-200	425						
$Ca(OH)_2$	210						
Water	50	6,000	4,800	19.4	19.4	1.73	
IMC-C	425						
IMC-C-200	425						
CaO	150						
Water	120	6,000	8,000+	14.9	15.1	1.90	
IMC-C	850						
CaO	150						
Water	120	6,000	7,125	12.4	12.5	1.97	
IMC-C	425						
IMC-C-200	425						
CaO	150						
Water	120	8,000	8,000+	14.1	15.0	1.89	
IMC-C	850						
CaO	150						
Water	120	8,000	6,813	11.2	11.5	1.98	
IMC-FC	425						
IMC-FC-200	425						
CaO	150						
Water	120	6,000					8 of 20 cracked in autoclave

TABLE IV continued

SAND-LIME BRICK COMPOSITIONS AND PROPERTIES

Composition		Pressing Pressure	Compressive Strength	Absorption		Apparent Specific Gravity	Remarks
Material*	Grams	psi	psi	Cold %	Boiling %		
IMC-FC	425						
IMC-FC-200	425						
CaO	150						
Water	150	6,000**	2,200	Let stand too long dry			1 of 10 cracked in autoclave
IMC-FC	425						
IMC-FC-200	425						
CaO	150						
Water	150	6,000	1,850	20.3	20.9	1.63	
IMC-FC	850						
CaO	150						
Water	150	6,000	5,937	17.8	18.1	1.73	
IMC-C	900						
CaO	100						
Water	120	6,000					18 of 20 cracked in autoclave
IMC-C	900						
CaO	100						
Water	120	6,000**					All cracked in autoclave
IMC-C	900						
CaO	100						
Water	120	6,000**	2,765	11.9	14.2	1.97	7 of 20 cracked in autoclave
IMC-C	450						
IMC-C-200	450						
CaO	100						
Water	120	6,000	6,237	9.6	9.3	1.90	
IMC-C	425						
IMC-FC	425						
CaO	150						
Water	120	6,000	5,012	8.2	8.9	1.93	

TABLE IV continued

SAND-LIME BRICK COMPOSITIONS AND PROPERTIES

Composition Material*	Grams	Pressing Pressure psi	Compressive Strength psi	Absorption Cold %	Absorption Boiling %	Apparent Specific Gravity	Remarks
IMC-C	900						
CaO	100						
Water	120	8,000					All bricks broken-water in pan after pressing
LT	900						
CaO	100						
Water	100	8,000					Disintegrated in autoclave because of high water level
LT	850						
CaO	150						
Water	120	6,000					
LT	850						
CaO	150						
Water	120	8,000					
LT	900						
CaO	100						
Water	100	6,000					
LT	900						
$Ca(OH)_2$	143						
Water	70	6,000	2,750	15.0	15.3	1.86	
LT	850						
$Ca(OH)_2$	210						
Water	50	6,000	2,275	14.5	15.5	1.93	

*Material Codes:
LT-Lawson tailings as received
LT-200 - Lawson tailings ground to minus 200 mesh
IMC-C - International Minerals and Chemical Corporation coarse tailings as is

TABLE IV continued
SAND-LIME BRICK COMPOSITIONS AND PROPERTIES

Material Codes continued:

IMC-C-200 - International Minerals and Chemical Corporation coarse tailings ground to minus 200 mesh.
IMC-FC - International Minerals and Chemical Corporation filter cake as is.
IMC-FC-200 - International Minerals and Chemical Corporation filter cake ground to minus 200 mesh.

**Hydrated after pressing at 60 psi for 30 minutes before curing.

TABLE V
FOAMED CALCIUM SILICATE TEST RESULTS

Composition (Grams)						Mixing Time (Minutes)			App.	Remarks
Sand No.1*	Sand No.2**	Cement White	Lime	H_2O	Aluminum	Mixer	Wet	After Aluminum Addition	SPG	
2,000	-	300	-	1,100	0.5	Paddle	10	2	1.28	Uncured-strong
-	2,000	-	300 CaO	1,100	0.5	Paddle	10	2	1.13	Soft uncured
1,000	1,000	860	-	1,080	0.75	Paddle	10	2	1.32	Strong****
1,000	1,000	800	100 CaO	1,040	1.5	Paddle	10	5	-	-
1,000	1,000	100	300 CaO	1,040	3.0	Paddle	10	5	-	Cracked
1,000	1000	100	400 CaO	1,100	1.0	Paddle	15	2	-	Poor expansion
1,000	1,000	100	400 CaO	1,100	1.5	Paddle	15	2	1.17	Poor expansion
1,000	1,000	100	400 CaO	1,100	2.0	Paddle	15	2	-	Poor expansion
1,000	1,000	100	400 CaO	1,300	1.0	Paddle	15	1	-	Broken
1,000	1,000	100	400 CaO	1,500	1.0	Paddle	15	1	0.98	Cracked
1,000	1,000	100	400 CaO	1,700	1.0	Paddle	15	1	0.73	Some cracking
1,000	1,000	100	570 $Ca(OH)_2$	1,200	1.0	Paddle	15	1***	1.00	Some cracking
2,000	-	100	570 $Ca(OH)_2$	1,200	1.0	Paddle	15	1***	0.98	Good appearance
3,000	3,000	300	1,710 $Ca(OH)_2$	3,600	3.0	Egg Beater	15	1***	0.94	Good appearance
2,000	2,000	200	1,140 $Ca(OH)_2$	2,400	2.0	Egg Beater	15	1***	0.93	Good appearance
-	4,000	200	1,140 $Ca(OH)_2$	2,400	2.0	Egg Beater	15	1***	0.94	Good appearance

*Lawson tailings as received
**Lawson tailings ground to minus 200 mesh
***30 seconds fast followed by 30 seconds slow
****Cured two weeks under water and not in autoclave

Part III

Evaluation of Feldspar Tailings for Brick and Glass Production

by

Billy M. Gay, Arthur E. Lucier, Robert F. Stoops

INTRODUCTION

The possibility of using the flotation tailings from the feldspar mining industry in the production of ceramic products was investigated. A literature survey was conducted in conjunction with experimental studies of the use of the tailings for glass and brick production. The results of the experimental work indicate possibilities of using the fine feldspar tailings for production of bricks and low-grade glasses such as might be used in foamed structural products. Additional research is needed to determine the full potential of these tailings for making ceramic products.

PROCEDURE

To investigate the possibilities of making glass from the tailings, no additions were made to the tailings and no special preparation was used. Samples of Feldspar Corporation's filter cake and Lawson-United tailings were placed in fireclay crucibles and fired to 2400°F and held for four hours. After firing, the crucibles were cut along their longitudinal axes, and the cut surfaces were examined visually. This procedure was repeated using samples of Feldspar Corporation's filter cake, International Mineral and Chemical Corporation's (IMC) filter cake, and Lawson-United tailings with a soak time of 30 hours at 2400°F. Samples of each of the five tailings streams, as well as a sample of the composite of the five streams, were then fired in fireclay crucibles at 2780°F for one hour. Again, the crucibles were cut along their longitudinal axes, and the cut surfaces were examined visually.

For the study of the brick-making qualities of the tailings, only IMC filter cake was used (See the discussion section of this report for the reasons for this decision.) All test specimens were extruded in a laboratory extruder using a water content in the feed material of approximately 23 w/o. The vacuum during extrusion was maintained at 15 inches mercury (guage). The die opening was 1 1/8" x 1 1/8", and the column was cut into 5" bars. Specimens consisting of IMC filter cake, IMC filter cake plus 3 w/o Volclay Western bentonite, and IMC filter cake plus 3.5 w/o Volclay Western bentonite were extruded Indentations were placed 10 centimeters (cm) apart on the top surfaces of all bars All specimens were dried for 10 hours at 230°F; and, after drying, samples of each composition were fired at 2020°F (cone 01) in an electric kiln. The kiln setting was two bars high with a one inch spacing between bars. Spacers cut from insulating brick were used to raise the top setting above the bottom setting

The color of the fired bars indicated that the kiln atmosphere was reducing. Three additional firings were made in an attempt to produce bars fired in an oxidizing atmosphere and at a uniform temperature. On the fifth firing, the temperature gradients were minimized and an oxidizing atmosphere was maintained by using a series of baffles and a ceramic tube running the length of the kiln near the bottom, through which air was introduced. The temperature of the air coming into the kiln was at or near the kiln temperature. Due to the necessity for repairs to the electric kiln, all subsequent firings were made in a propane gas fired kiln. Because of the initial results achieved with a firing temperature of 2020°F, these firings were made at 2151°F (cone 5).

Several firings were made in the gas fired kiln in an effort to achieve uniformly fired bars; and again, the temperature gradients had to be minimized and secondary air was necessary to achieve oxidizing conditions.

After firing, the distance between the indentations on the tops of the bars was measured The difference between this measurement and 10 centimeters when divided by 10 and multiplied by 100 gave the percent linear shrinkage. After weighing (dry weight), the bars were submerged in a tank of water at room temperature and soaked for 24 hours They were removed and weighed after excess water had been wiped off with a damp cloth. The difference between this weight and the dry weight when divided by the dry weight and multiplied by 100 gave the percent cold-water-soak absorption. The bars were returned to the water and boiled for five hours, cooled, removed and reweighed. The difference between this weight and the dry weight, when divided by the dry weight and multiplied by 100 gave the percent-boiling-water absorption. One inch sections were cut from each bar after drying for 24 hours at 235°F. These one inch sections were broken in compression to determine the compressive strengths of the fired bars. The remaining portion of each bar was placed in a testing machine using a three point loading system and broken in a transverse mode to determine the modulus of rupture of the fired bars.

RESULTS AND DISCUSSION

Visual examinations of the glass samples were the only evaluations used. Under the three sets of melting conditions investigated, the coarse tailings from Feldspar Corporation and IMC, the tailings from Lawson-United, and the composite of all tailings contained more than 50% of undissolved particles. Thus, these tailings appear to be too refractory for normal glass production without the addition of significant amounts of fluxes to lower the temperatures at which they melt completely The glassy portions of these materials contained air bubbles, which indicates that the viscosities of the glasses were relatively high. The glass phases were olive drab in color when fired at 2400°F and light to medium gray color when fired at 2780°F. Both of these colors would be undesirable for most commercial applications. Improvement in the color probably could be obtained by further benefication of the tailings and by addition of colorants. Since the objective of this investigation was to explore possible uses for the tailings without additions or benefication, the addition of colorants or fluxes was not investigated.

The glasses made by melting Feldspar Corporation's filter cake all contained about 30% undissolved particles. Thus, no difference was observed in this material when it was held for four hours and for thirty hours at 2400°F. Also, firing at 2780°F for one hour did not cause any observable change in the amount of undissolved material. In all of the firings of the IMC filter cake, about 5% of the resulting material consisted of undissolved particles. All of the glasses made from filter cake tailings contained bubbles also. They were much smaller and more numerous in the materials fired at 2780°F. The one hour firing time at this temperature was not sufficient to permit coagulation or elimination of the bubbles.

Table I shows that Feldspar Corporation's filter cake had much smaller particle size than the coarse tailings. Table II shows that the mineral compositions of Feldspar Corporation's coarse tailings and filter cake were quite similar Therefore, it is felt that particle size and not composition difference was the major factor causing the increased amount of glass in the fired filter cake from Feldspar Corporation as compared to the fired coarse tailings from this company The IMC filter cake was by far the finest of the tailings investigated, Table I; however, it had significantly lower quartz content and higher clay mineral content than any other tailings, Table II. It is not known to what degree these factors were responsible for the very high percentages of glass obtained in the IMC filter cake.

At 2400°F Feldspar Corporation's filter cake produced a medium brown glass, whereas IMC's filter cake produced a dark brown glass. At 2780°F both materials produced a light gray glass.

Without any additions or alterations it appears that a low quality glass could be made from IMC's filter cake and possibly from Feldspar Corporation's filter cake. Such a glass might be used in making foamed glass insulating panels in which color and small amounts of undissolved particles would not be critical In the production of such foamed insulation the addition of fluxes probably would be highly desirable to produce a glass with an acceptable viscosity at a reasonable firing temperature.

Attention was focused on the possibility of making bricks using the tailings as the major raw material. It was decided that efforts would be centered around the IMC filter cake, since the clay mineral content is substantially higher than in the other tailings (see Table II) and the particle size is less (see Table I). The higher clay mineral content imparted a slight amount of plasticity to aid in forming The smaller particle size indicated better extrudability and lower firing temperature, as well as a stronger, more durable fired product

It was found that the IMC filter cake could be extruded when mixed with 23.5% water, but, the bars could not be lifted off the forming board and placed on the dryer rack without considerable distortion. When fired, these bars were extremely sensitive to temperature variations and kiln atmosphere. Even under the most carefully controlled laboratory conditions of firing, nothing which could be called a satisfactory specimen was produced. All bars, after firing, were distorted to the point of preventing measurement of shrinkage, compressive strength, or modulus of rupture. They all showed variations in degree of vitrification, not only from bar-to-bar, but from end-to-end of the same bar.

To enhance extrusion of the bars, the addition of a plasticizer was deemed necessary; and, due to its highly plastic nature, bentonite was selected to minimize the required addition. Bars were extruded with 3% and 3.5% bentonite addition and with 23% water. These compositions extruded well with no noticeable distortion of the bars when they were transferred from the forming board to the dryer rack After being fired to 2020^{o}F (cone 01) in the electric kiln, the bars were punky sounding when tapped together and were far short of meeting ASTM specifications for either Grade SW or MW bricks, Table III. They, also, were found to be very sensitive to kiln temperature gradients, kiln atmosphere, and to the presence of any weight placed upon them during firing When set two-high during firing, the bottom bars were found to be almost flat under the points of contact after firing When set one-high during firing, even the cone plaque set on top of the bars caused a noticeable flatting

When bars were fired in the gas kiln at cone 5, the same problems were apparent and no bars acceptable for property measurements were produced during the first firing During the second firing, the setting was one high and consisted of five bars. These bars were acceptable for property measurements, and the properties determined are shown in Table III along with the properties of the bars fired at 2020°F in the electric kiln Also shown in Table III are the ASTM specifications for Grade MW and Grade SW bricks. The bars fired at 2151°F (cone 5) exceeded the requirements for Grade MW and Grade SW bricks.

The rate of firing was not found to be critical In the electric kiln, the rate was controlled at 150°F per hour. Due to the lack of control which existed in the gas kiln, the total firing time was less than two hours.

CONCLUSIONS

Based on the results of this investigation the following conclusions appear to be justified

1 With the possible exception of the IMC filter cake, it is doubtful that an acceptable glass could be produced from these tailings as they are. Benefication to remove such things

as mica and iron minerals and the addition of alkali metal oxide fluxes to the tailings might permit production of low grade glasses. Even then, there is no guarantee that a glass with acceptable properties could be produced.

2. Some of these tailings probably could be used as brick raw materials; however, the process variables such as kiln atmosphere and kiln temperature gradients must be carefully controlled. Further, a complete investigation of forming and firing characteristics would be necessary for each tailings stream, and the addition of a plasticizer probably would be necessary for forming and firing. This could be a serious economic limitation.

3. The bricks would most likely have to be set one high in order to minimize distortion during firing.

4. Much more research is needed to investigate fully the firing characteristics of these tailings in making ceramic products.

TABLE I

SCREEN ANALYSIS OF TAILINGS SAMPLES (BASED ON SAMPLES COLLECTED OVER A 10 WEEK PERIOD*)

COMPANY	MATERIAL	SIZE (TYLER MESH) IN PERCENT											
		+20	-20 +28	-28 +35	-35 +48	-48 +65	-65 +100	-100 +150	-150 +200	-200 +270	-270 +325	-325 +400	-400
Lawson-United	Tailings	3.1	6.1	9.1	11.8	11.4	11.4	12.2	11.3	6.7	5.6	3.1	8.0
Feldspar Corporation	Filter Cake	0.2	0.8	1.6	2.7	4.0	6.9	10.2	12.1	10.2	11.3	5.4	34.6
Feldspar Corporation	Coarse Tailings	4.1	18.5	25.3	21.2	13.3	8.3	4.5	2.2	0.9	0.7	0.3	0.8
IMC	Filter Cake	-	0.2	0.5	0.7	0.8	1.1	1.8	3.9	9.9	14.2	7.1	60.0
IMC	Coarse Tailings	1.6	10.4	17.1	14.9	11.2	10.6	10.3	9.6	5.2	4.4	1.6	3.1

*Taken from U.S.B.M., Project No. G 0180 260 April 1969 - Progress Report by Immo H. Redeker

TABLE II

MINERAL COMPOSITION OF TAILINGS SAMPLES (BASED ON SAMPLES COLLECTED OVER A 10 WEEK PERIOD*)

COMPANY	MATERIAL	MINERAL COMPOSITION (PERCENT)				
		Feldspar	Quartz	Mica	Fe Minerals	Clay Minerals
Lawson-United	Tailings	50	40	5	2	3
Feldspar Corporation	Filter Cake	45	40	8	2	5
Feldspar Corp.	Coarse Tailings	50	40	3	3	4
IMC	Filter Cake	50	30	5	2	13
IMC	Coarse Tailings	40	50	4	3	3

*Taken from U.S.B.M. Project No. G 0180 260 April 1969 Progress Report by Immo H. Redeker

TABLE III

PROPERTIES DETERMINED ON FIRED BARS FORMED FROM IMC FILTER CAKE PLUS 3.5% BENTONITE AND ASTM SPECIFICATIONS FOR GRADE SW AND GRADE MW BRICKS

PROPERTY	SPECIMENS FIRED[1] to 2151°F (cone 5)	SPECIMEN FIRED[1] to 2020°F (cone 01)	ASTM REQUIREMENTS FOR GRADE SW BRICK	ASTM REQUIREMENTS FOR GRADE MW BRICK
Percent Linear Drying Shrinkage	1.4	1.5	--	--
Percent Linear Firing Shrinkage	9.9	3.8	--	--
Percent Boiling Water Absorption	10.6	26.2	17.0[2] / 20.0[3]	22.0[2] / 25.0[3]
Modulus of Rupture (psi)	3,170	1,630	--	--
Compressive Strength (psi)	8,980	3,360	3,000[4] / 2,500[5]	2,500[4] / 2,200[5]
Color	Light gray with beige dots	Salmon	--	--

1 Average of five specimens

2 Maximum allowable for average of five specimens

3 Maximum allowable for individual specimens

4 Minimum allowable for average for five specimens

5 Minimum allowable for individual specimens

Part IV

Feldspar Tailings Utilization for Construction Purposes

by

Grigg Mullen

INTRODUCTION

A limited program of investigation has been undertaken to determine the potential usefulness of mineral tailings from various feldspar mining operations for incorporation into construction work. Emphasis has been placed upon use as fine aggregates and mineral fines for Portland cement mortars and bituminous concrete mixtures and use of stabilized fines for base course foundation materials.

The tailings themselves vary according to source and processing operation from medium-fine stone sands to fine rock flours. The stone sands have been examined for mortar making properties using Portland cement and for use in sand asphalt paving mixtures. The rock flour materials have been examined for stabilization for foundation and pavement base courses using Portland cement and combinations of Portland cement, lime, and fly ash. All materials have been used with gradation as received. It was believed that any attempt to sort or blend materials for improved gradation would result in costs that would be prohibitive.

The findings of the laboratory tests vary in promise:

(1) The stone sands can be used to make mortars of acceptable strength and workability. However, the water and cement requirements are such that they are marginal competitors with natural sands at best.

(2) The stone sands can be used to make sand asphalts of acceptable strength and stability. Asphalt cement requirements are near normal, and this potential use deserves further development.

(3) The rock flours vary in quality, but they can be satisfactorily stabilized with Portland cements. They can also be stabilized with combinations of Portland cement, lime, and fly ash. Rock flours so stabilized should lend themselves readily to use as foundation layers for structures and for low-cost roads. This area shows much promise for success, and comprehensive studies to develop specific guidelines for use are warranted. Of particular interest is the implied success of stabilization with fly ash, another waste product of industry.

In the pages that follow, test procedures and study data will be presented and discussed. Five areas that will be treated are Materials, Bituminous Mixtures, Portland Cement Mortar, Soil Cement, and Cement-Lime-Fly Ash Stabilization.

MATERIALS

Five tailings products that have been tested are identified in Table I. They are from three sources and vary from fine rock flours to medium to fine stone sands. Materials passing #200 sieve vary from 2 to 92% and mica contents from 10 to 13%. Mica for mortar and stabilization work is considered an undesirable component. The major portion of each material is quartz and feldspar, both desirable minerals for construction uses.

Portland cement used has been an ASTM Type 1, a commercially available cement.

Lime was mason's slaked lime normally used in masonry work.

Fly ash was obtained from Carolina Power and Light Company and is a stack precipation product from burning of coal in power plants. Fly ash used was a run of stack material with no special processing.

Asphalt cement was normal ASTM 85-100 penetration asphalt meeting North Carolina State Highway Commission specifications.

BITUMINOUS MIXTURES

Coarse tailings numbers 4 and 5, Table 1, were sieved for gradation, and gradations were compared to Asphalt Institute recommended mix composition 175-4, Table IV-10, p. 66 (1)*. Gradation limits are plotted in Figures 1a and 1b for mix compositions VIIIa and VIIa, the mixes most nearly conforming to tailings gradations 4 and 5, together with the gradations for tailings 4 and 5. The mixture shown for VIIIa is a sheet asphalt and for VIIa is a sand asphalt. In general, sheet asphalts are used for city street surface mixes, while sand asphalts are used for rural, low-cost roads.

Trial batches of bituminous concrete were made in the laboratory using a graded tailings and according to ASTM Designation D1559-65, "Resistance to Plastic Flow of Bituminous Materials Using the Marshall Apparatus". Asphalt

*Numbers in parenthesis refer to list of references at end of text.

cement content was varied from 8% to 12% of weight of aggregate in 2% increments. Three specimens were made at each asphalt cement content for one round of testing. Two rounds were tested and results recorded in Table II.

Interpretation of results in comparison to other materials that meet ASTM and Asphalt Institute specifications is that the sheet asphalt mix using tailings No. 4 would be marginal for stability for resistance to load. The sand asphalt mix using tailings No. 5 would be acceptable for rural low-cost roads with asphalt cement content (10% optimum) running about normal for this type of mix in North Carolina. Tailings No. 4 could probably be used as a substitute sand-asphalt material taking into account that the optimum asphalt content (12%) is higher than normal.

In summary, tailings 4 and 5 can be used for sand asphalts, but use would probably not be competitive where other aggregates are in plentiful supply.

PORTLAND CEMENT MORTAR

Tailings 4 and 5, Table I, were compared for mortar making proportion to a natural silica mortar sand meeting requirements of ASTM Designation C144-66T, "Aggregate for Mortar Masonry". An ASTM Type I Portland cement was used throughout (ASTM Designation C150-68, "Portland Cement"). Cement was normalized according to ASTM Designation C187-64, "Normal Consistency of Hydraulic Cement".

Mixtures were made using the mortar sand and the two tailings materials in ratio by weight of cement to sand of 1:1, 1:1½, and 1:2. Flow properties were determined for each mixture and results are compared in Figure 3 where flow is plotted versus water-cement ratio by weight. Water-cement ratio comparison at constant flow of 180 is shown in Figure 4. Flow tests were performed according to ASTM Designation C-109, "Compressive Strength of Hydraulic Mortars". The flow used herein is the spread of the mortar at completion of test computed as a percentage of the original mold diameter.

Setting times for each combination were checked to determine presence of undesirable chemical effects from tailings. Results shown in Table III were negative; that is, no undesirable effects were observed

Compressive strength specimens (2" diameter, 4" high) were manufactured for tests at 7 and 28 days age for all mixtures at 180 flow. Results are given in Table IV and compared on a percentage basis in Figure 5 Results are an average of three specimens per round and for three rounds of testing. Each value is the average of nine individual tests.

Tailings 4 and 5 can be used to make satisfactory mortars. Mortars tend to be harsher than those made with natural sand, to require more water for a given consistency or flow, and to exhibit lower strength properties at equal flow.

In summary, where natural sands are in sufficient supply, tailings would probably not be competitive for mortar uses.

SOIL CEMENT

Tailings 1, 2, and 3, the finer materials, were stabilized using ASTM Type I Portland cement at percentages by weight ranging from 2% to 8% in 2% increments. Sufficient water was added to make a cohesive mix for molding purposes. Mixes exhibited no flow properties.

Specimens which were 2" diameter by 4" high were molded for compressive strength determination at age 7 days. Results are given in Table V and compared graphically in Figures 6 and 7.

Results for the soil cement work are quite promising. Comprehensive tests to establish guidelines for use are warranted. Material could be stabilized for road base or sub-base by pug mill at production site or by pulvimixers in place on the road. Advantage to rock flours for this type of stabilization is their initial non-plastic properties that allow them to be mixed readily with stabilizing additives.

SOIL-CEMENT-LIME-FLY ASH STABILIZATION

A soil that is used for pavement or other foundation purposes is compacted in some standard manner using rollers, tampers, or vibrating equipment to increase the in-place density and thereby the strength or supporting value. Density is sensitive to moisture content of the soil, and there is one moisture content for each soil at which maximum density is obtained for a given compaction effort. This moisture content is called the <u>optimum moisture content</u>. Soils or rock flours to which minimal cementing agents are added exhibit the same general compaction properties as ordinary soils and have an optimum moisture content. Compaction is accomplished before cementing action begins. The water acts first as a lubricant for compaction and then combines chemically with the cement to bind the soil or rock flour mixture to increase its strength.

It was demonstrated that these rock flour tailings could be stabilized with Portland cement in the previous section of this report. Other materials by themselves or in combination with small amounts of Portland cement develop hydraulic cementing properties to bind particles together Two of these materials are $Ca(OH)_2$ slaked lime, and fly ash. Fly ash is a stack precipitate from coal burning operations that contains finely divided SiO_2, some other oxides, and some carbon or lamp black. Fly ash is a pozzolanic material

Major work with stabilization of dune sands has been done by the Port of New York Authority utilizing Portland cement-lime-fly ash combinations as the cementing material (2, 3). It has been attempted to extend this work to rock flours in this investigation.

Compaction properties of rock flours and cementing combinations were determined in the laboratory for mixtures shown in Table VI. Compaction curves fell into groups or families for the two tailings tested, and two curves for each are shown in Figure 8.

Compressive strength cylinders 2" in diameter by 4" high were molded utilizing laboratory compaction procedures and tested at age 7 days Results for various mixtures are given in Table VII. Increase in strength from addition of lime and fly ash is shown in Figure 9.

Results of the limited tests conducted are promising and warrant full scale investigation for extension to other combinations and for strength at later ages.

SUMMARY

Coarser sand size tailings will make satisfactory sand-asphalt type bituminous mixtures for low-cost road surfacings. Further developmental work in this area is warranted.

Coarser sand size tailings will make Portland cement mortars of acceptable strength and workability but at higher probable cost than mixtures utilizing natural sands. Further work in this area is not recommended.

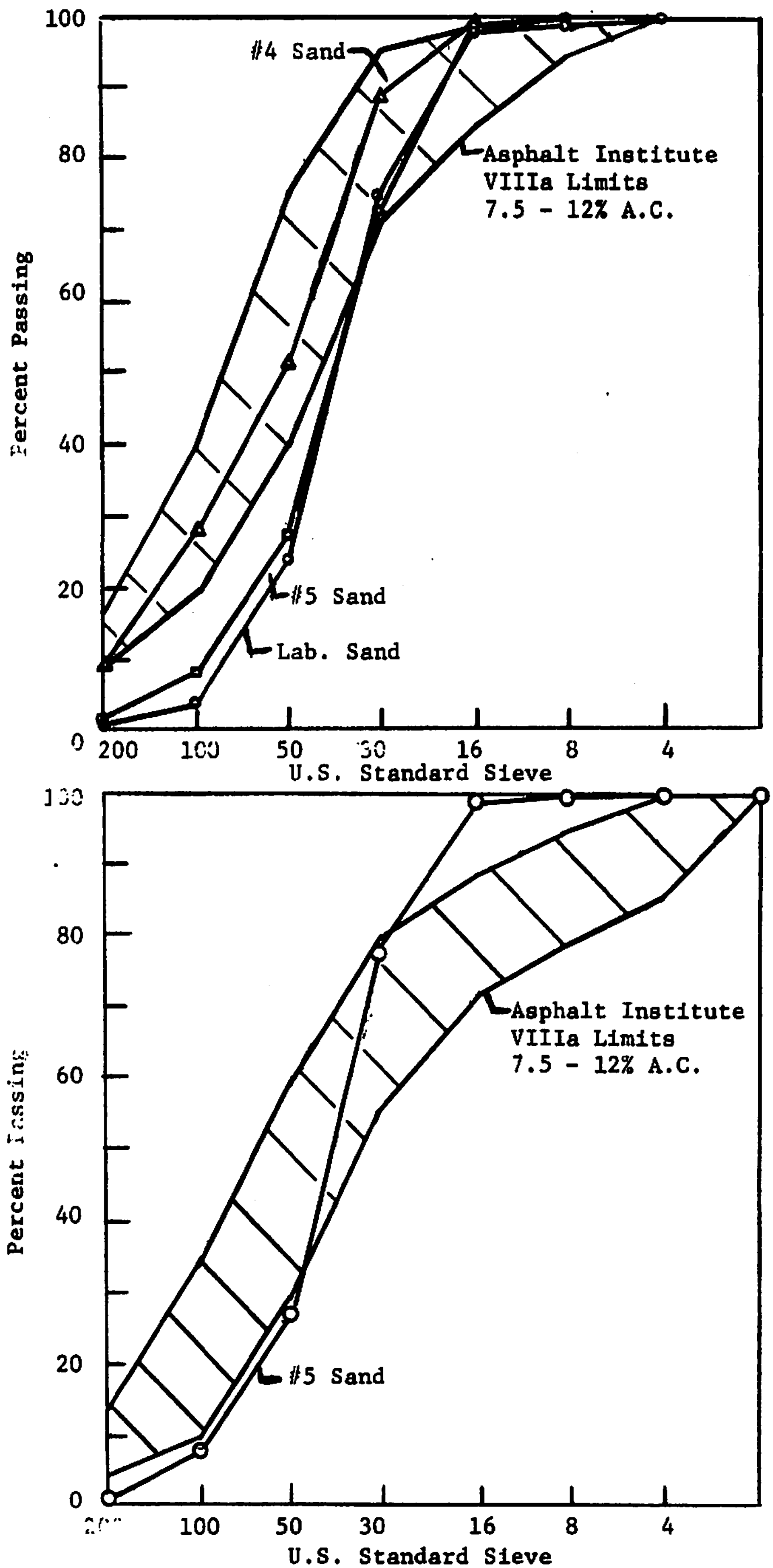
Fine rock flour tailings may be stabilized using Portland cement and Portland cement-lime-fly ash combinations for pavement and other foundation layers. Further work in this area is warranted and recommended.

LIST OF REFERENCES.

1. The Asphalt Handbook (MS-4), April, 1965 edition, The Asphalt Institute, College Park, Maryland.

2. Nai C. Yang, "Flyash Captures New Market," Power, September, 1968.

3. Nai C. Yang, private communication, January, 1969.



(a)

(b)

Figure 1a, 1b. Comparative Gradation for Bituminous Mixes.

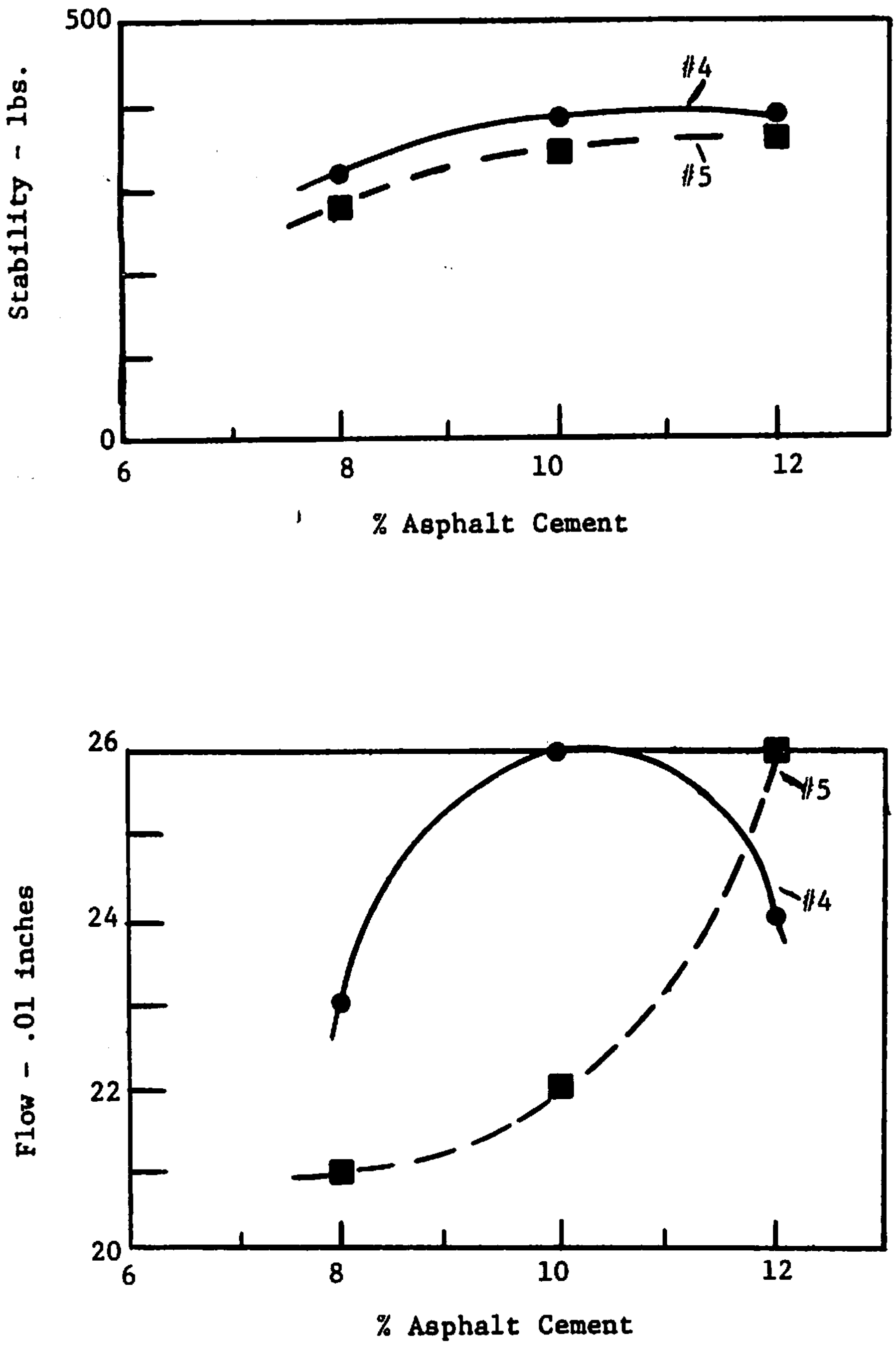


Figure 2. Bituminous Mix Marshall Test Results.

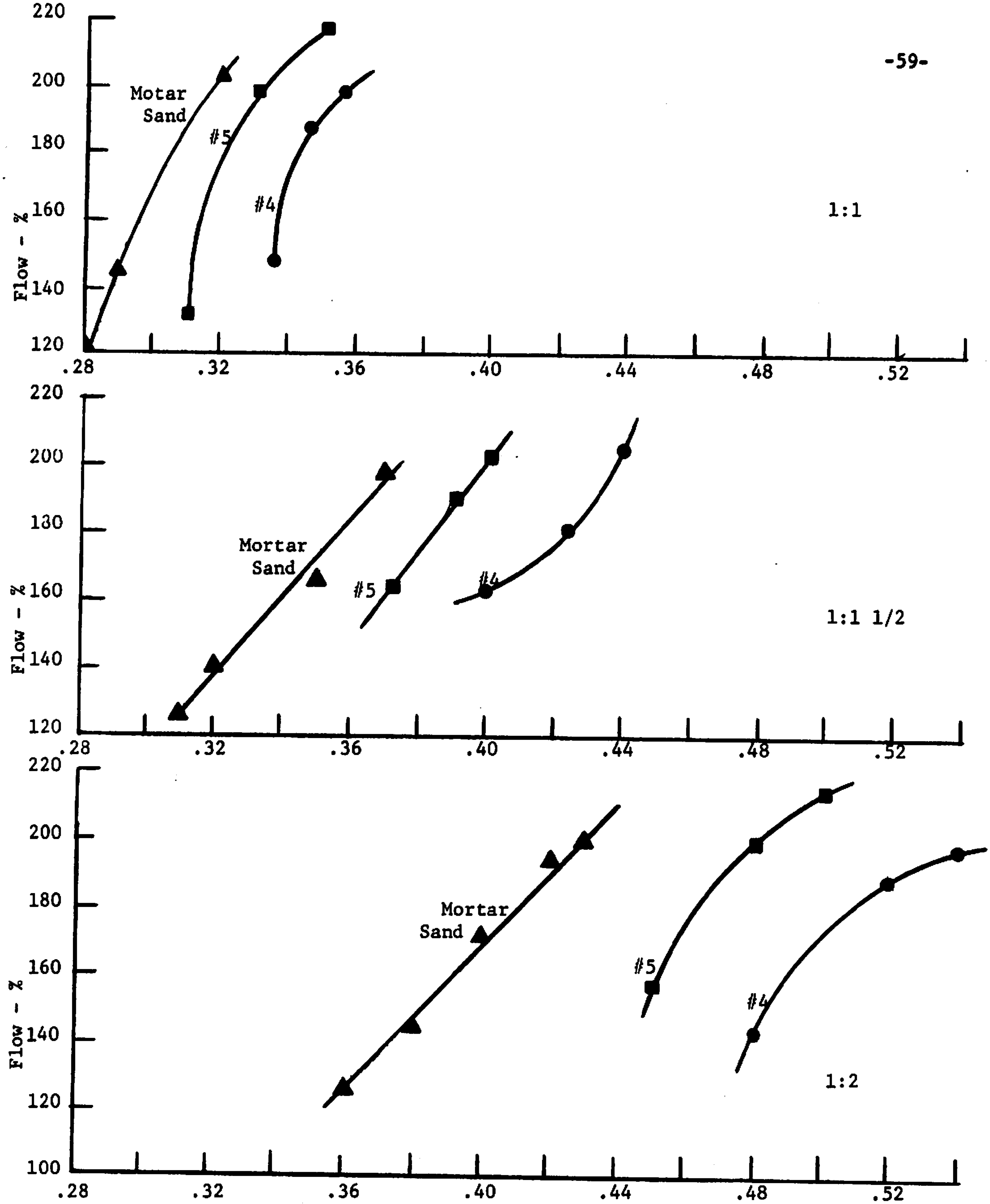


Figure 3. Flow vs Water-Cement Ratio

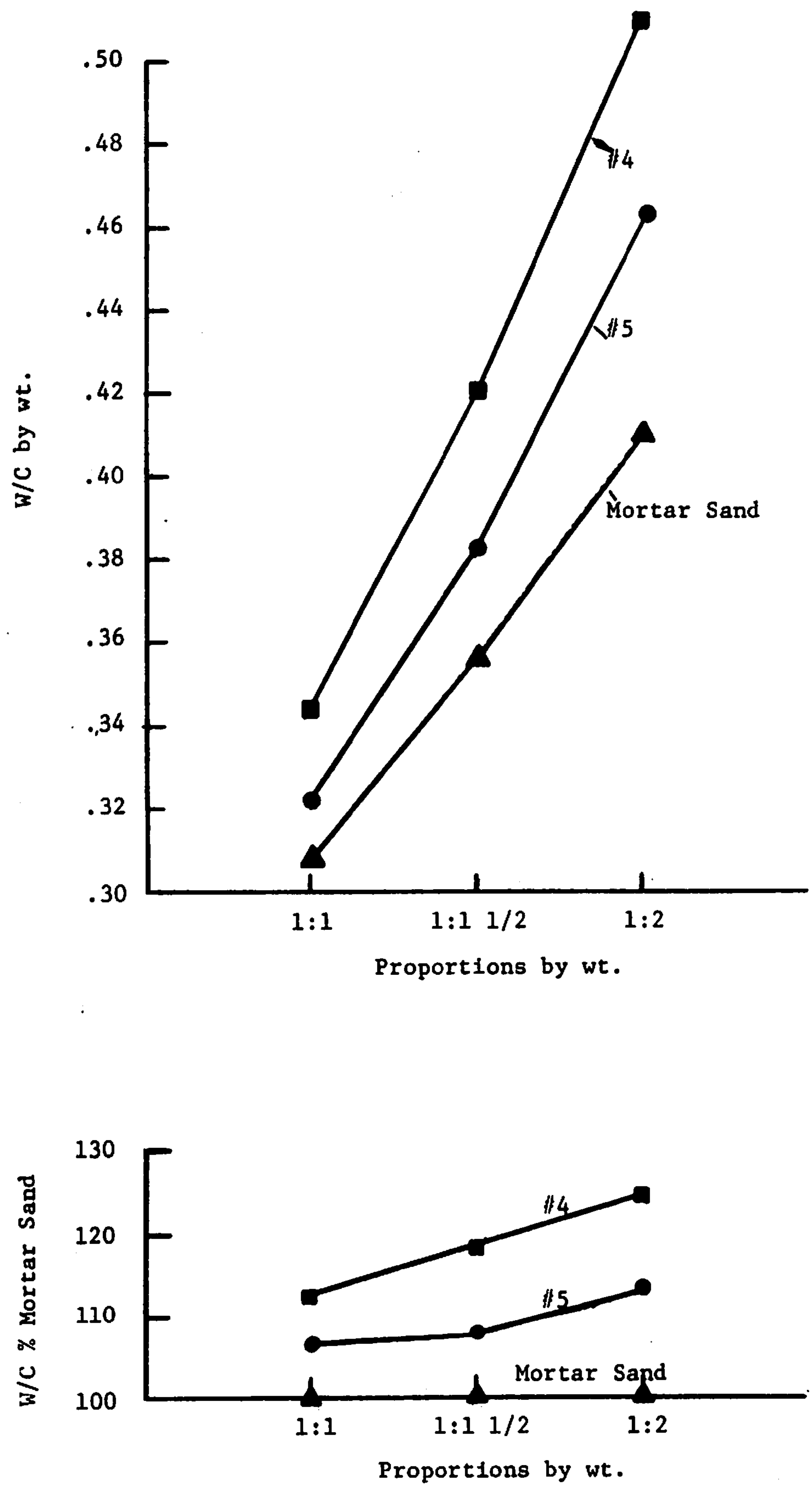


Figure 4. Water-Cement Ratio at 180 Flow.

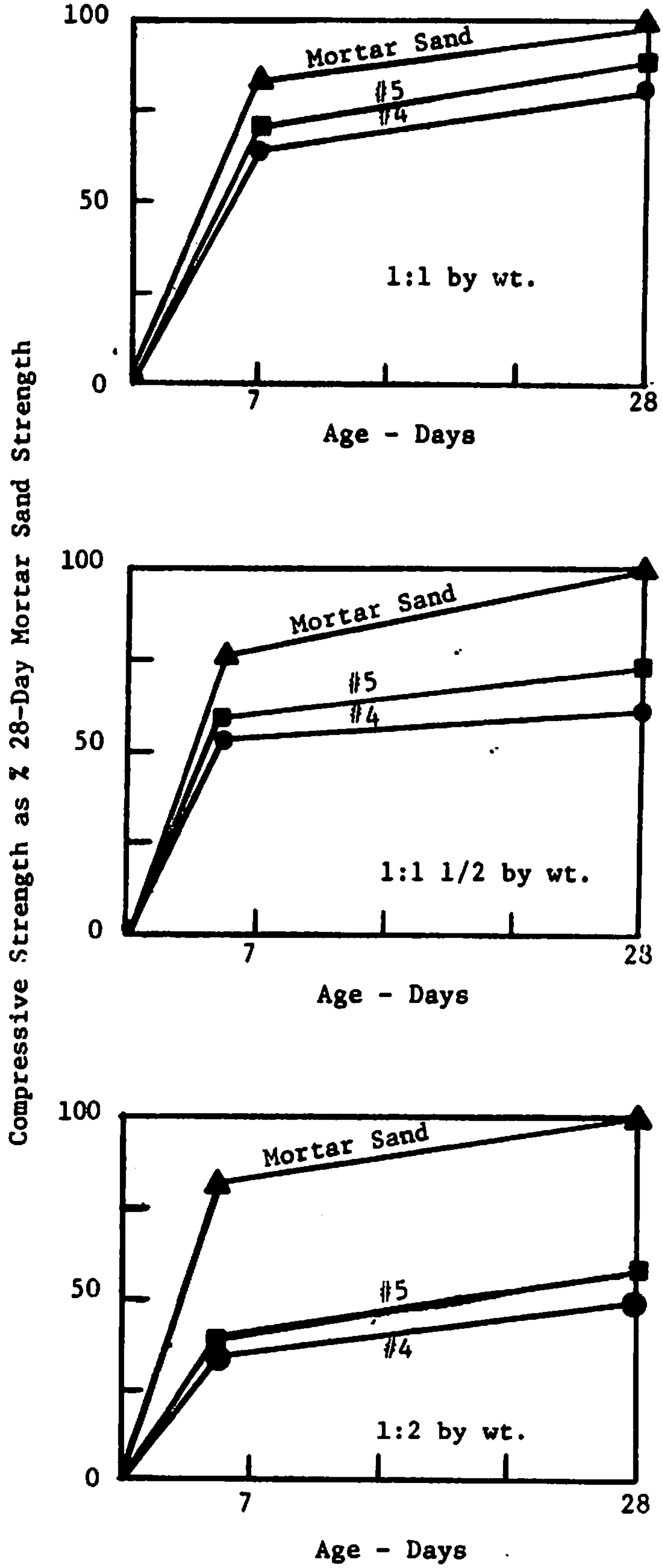


Figure 5. Strength Comparisons for Mortar Mixes.

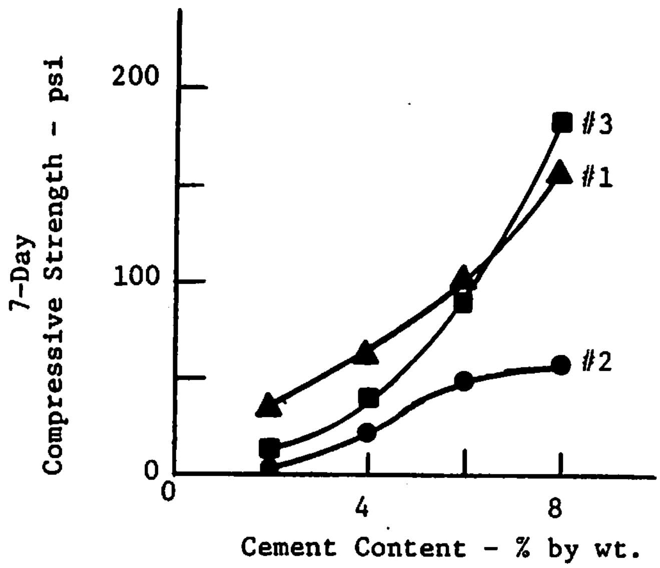


Figure 6. Soil Cement 7-Day Strength vs Cement Content.

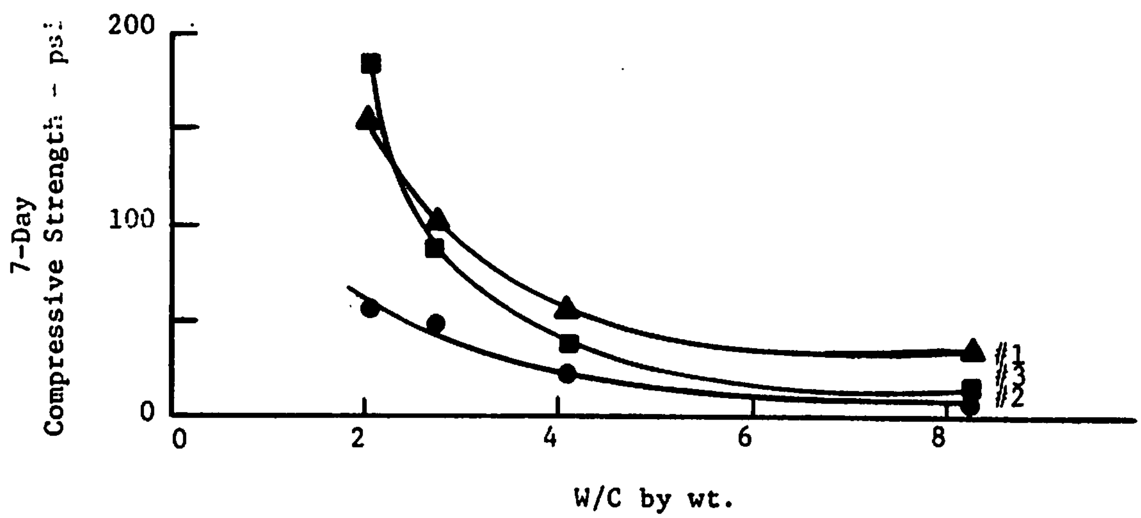


Figure 7. Soil Cement 7-Day Strength vs W/C by Wt.

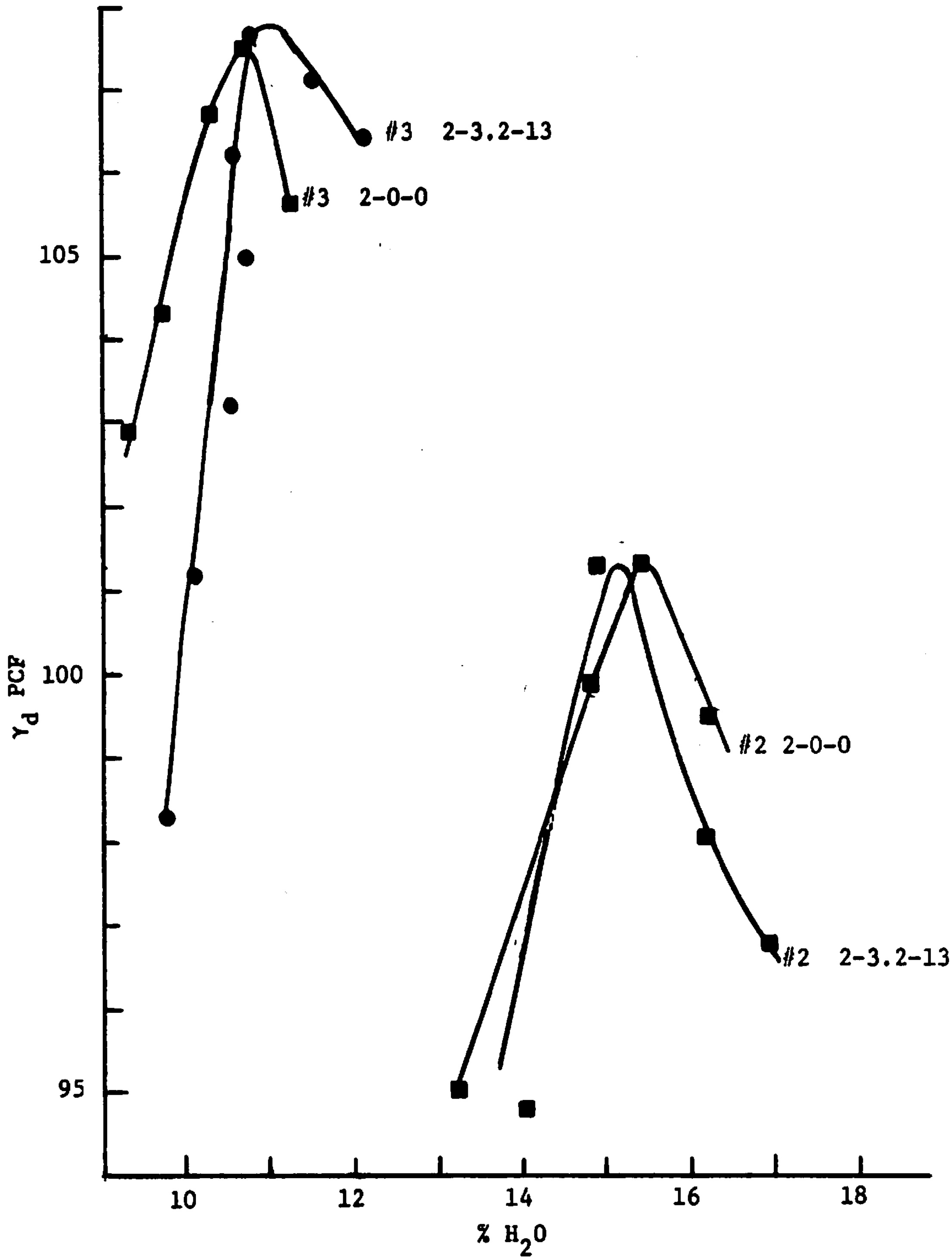


Figure 8. Compacted Dry Density vs Moisture Content.

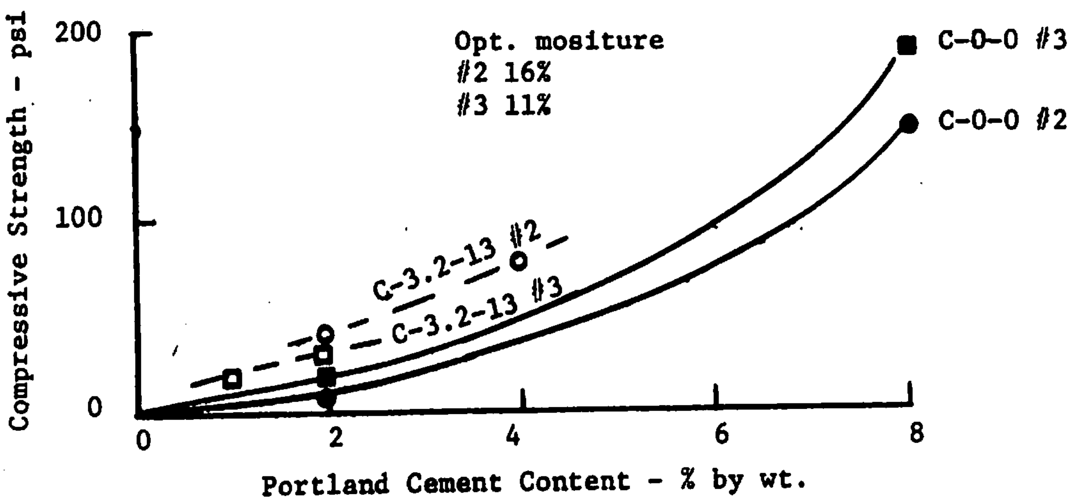


Figure 9. Strength Comparisons for Various Cementing Combinations.

TABLE I

MINERAL MATERIALS

Identification Number	Description	Source
1	Tailings	Lawson-United
2	Filter Cake	IMC
3	Filter Cake	Feldspar Corp.
4	Coarse Tailings	IMC
5	Coarse Tailings	Feldspar Corp.

TABLE II

BITUMINOUS MIXTURE TEST RESULTS

Tailings Sample Number	Asphalt Cement % of Aggregate by Weight	Marshall Flow .01 inches	Marshall Stability pounds
4	8	23	312
	10	26	385
	12	24	
5	8	21	285
	10	22	342
	12	26	351

TABLE III

SETTING TIME IN MINUTES FOR MORTAR MIXES

Mix by Weight	Mortar Sand	Number 4	Number 5
1:1	150 min*	170	150
1:1½	145	153	155
1:2	150	150	135

*Setting time for all mixes at flow of 200.

TABLE IV

COMPRESSIVE STRENGTH FOR MORTAR MIXES

Mix by Weight	Mortar Sand		Number 4		Number 5	
	7 Days	28 Days	7 Days	28 Days	7 Days	28 Days
	Compressive Strength in Pounds per Square Inch					
1:1	12000	14450	9280	11700	10100	12900
1:1.5	10630	13880	7500	8350	8110	10140
1:2	9650	11880	4080	5890	4670	7060
	Compressive Strength as % of 28 Day Strength of Mixes with Mortar Sand					
1:1	83.0	100	74.2	81.0	70.0	89.4
1:1.5	76.6	100	54.0	60.2	58.5	73.1
1:2	81.2	100	34.4	49.5	39.4	59.5

TABLE V

SOIL CEMENT PROPERTIES

Tailings Sand	Percent of Portland Cement by Weight 2	4	6	8
	7 day Compressive Strength - psi*			
1	33.5	61.6	100.9	158.1
2	6.0	21.0	49.1	55.7
3	14.4	38.2	88.1	183.3
	Unit Weight at Modling - pcf			
1	102.7	101.6	103.7	102.4
2	89.5	89.1	91.9	89.4
3	103.5	110.2	101.6	112.5
	Water/Cement ratio by weight			
1	8.25	4.13	2.75	2.06
2	8.25	4.13	2.75	2.06
3	8.25	4.13	2.75	2.06

*Specimens were cured 7 days in standard moist room.

TABLE VI
COMPACTION COMBINATIONS: CEMENT-LIME-FLY ASH MIXTURES

Sand 2	Sand 3	Portland Cement % by wt.	Lime %	Fly Ash %
x	x	2.0	0	0
x	-	8.0	0	0
x	-	0	3.2	13.0
x	x	1.0	3.2	13.0
x	x	2.0	3.2	13.0

TABLE VII
SEVEN DAY STRENGTH AT OPTIMUM MOISTURE: CEMENT-LIME-FLY ASH MIXTURES

C-L-F Mixture	Sand 2		Sand 3	
	psi	% water*	psi	% water*
2-0-0	6	16.5	21	10.9
8-0-0	150	16.0	183	10.9
1-3.2-13	-	-	24	10.9
2-3.2-13	40	16.25	26	10.9
4-3.2-13	77	16.25	-	-

*Water computed as percent of dry mixture.