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AN INVESTIGATION INTO THE USE OF WASTE COAL-MINE SHALE FROM NEW BRUNSWICK AS A SOURCE OF LIGHTWEIGHT AGGREGATE

by

V. A. HAW, H. S. WILSON AND N. G. ZOLDNERS

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SUMMARY OF RESULTS

Samples of waste coal-mine shale were used to produce lightweight concrete aggregate by bloating in a rotary kiln and by the sintering process.

Physical properties of these products indicate their suitability for use as aggregate in lightweight concrete.

Trial mixes and tests conducted on the hardened concrete indicated that a high quality structural lightweight concrete can be produced with this aggregate.

Whether a rotary kiln or sintering process should be used, depends on several technical and economic factors. Type of aggregate available on the market, capacity of the plant, type of fuel, and other factors must be considered before selecting the best suitable manufacturing process.

*Formerly Senior Scientific Officer, **Scientific Officer and ***Senior Scientific Officer, Mineral Processing Division, Mines Branch, Department of Mines and Technical Surveys, Ottawa, Canada.

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INTRODUCTION

Some time ago the Fuels Division of the Mines Branch submitted a sample of shale from the Minto coal field of New Brunswick for investigation into its use as raw material for the production of lightweight aggregate. In addition to the purpose of developing local industry it was hoped that some use could be made of the shale refuse containing large amounts of coal now being discarded. Subsequently a visit was made to the Minto area by V. A. Haw where first-hand observations were made on the possibilities of establishing a lightweight aggregate plant. At that time arrangements were made to have a large bulk sample obtained of the shale for a complete test program at the Mines Branch laboratories. T. E. Tibbetts of the Fuels Division procured samples of parting shale (containing a high coal content) from the King mine and roof shale from the Avon mine.

The purpose of the work reported on herein was to determine the expanding qualities of the shale; to investigate methods of produttion of lightweight aggregate from the shale; and to provide information on the concrete-making qualities of the lightweight aggregate produced.

Location and Description of Deposit

The Minto coal field lies about 30 miles northeast of Fredericton, New Brunswick. A number of companies are mining the deposit by both stripping and underground methods. A typical stripping operation which was visited is that of the Avon Coal Co. Ltd. The coal seam occurs at a depth of about 75 feet. A dragline removes all the overlying waste rock to a spoil pile and the coal is recovered by a mechanical shovel. The operation is illustrated at the end of this report. Other properties visited included those of the Miramichi Lumber Co. Ltd., A. W. Wassen Ltd., and McMean Ltd.

The stratigraphic sequence of formations starting at the top includes an overlying surface till which is underlain by 10-ft of red clay (good for brick manufacture), followed by a 20-ft bed of sandstone which overlies the shale. The shale bed varies in thickness to 20-ft or more. It is this shale which is of principal interest for use in lightweight aggregate production. It is bluish-grey in colour, fissile, and very uniform. After short exposures to the air it slakes readily. The coal seam directly under the shale varies between 12 and 20 in. in thickness and is itself parted by a variable thickness of shale dividing it into two layers.

Description of Samples

The shale samples received for testing consisted of 500-lb of roof shale from the Avon pit, and about the same amount of parting shale from the King mine. In addition, a sample of coal from the King mine was obtained to use as a source of fuel for the sintering tests.

The roof shale was similar to that described above. The parting shale, however, contained about 50 per cent coal. Owing to this high coal content there was no purpose in considering it as a potential source of lightweight aggregate. If sintering was used as a method of production it might be interground with the clean shale and used as a source of fuel. However, for our work here we did not attempt to use the parting shale, but rather the coal, which was blended with the roof shale for our sintering work.

LIGHTWEIGHT AGGREGATE INVESTIGATION

Preparation of Samples

The shale as received was crushed in an impact crusher and screened on 1/2 in., 1/4 in., and 6 mesh screens. The + 1/2-in. was returned to the crusher for further reduction. The - 1/2 + 1/4 in., and - 1/4 in. + 6 mesh fractions were used for rotary kiln tests, and the -6 mesh material for sintering.

Preliminary Bloating Tests

Preliminary tests were made in a small gas-fired muffle kiln to determine the relative amount of bloating and the approximate temperature range over which bloating occurred. These tests were made on shale sized - 1/2 + 1/4 in. The charges of shale were placed in the kiln at temperature intervals of 50 degrees from 1900° to 2100°F. They were retained in the kiln for periods of 4, 8, and 12 minutes at each temperature. On removal they were examined for bloating. Results are shown in Table 1.

Production of Lightweight Aggregate

There are two standard methods of producing lightweight aggregate from shale or clay; (A) by rotary kiln, and (B) by sintering. Each has its advantages under certain conditions. There are no sintering grates operating in Canada for production of lightweight aggregate, although in the United States they account for about 30 per cent of the total number of plants producing lightweight aggregate.

The sintering method probably is more economical with regard to unit cost of production where large outputs are involved, i.e., 400 cu yds per day, or more. It also is superior where the bloating range of the material is limited. The bloating range refers to the point between incipient fusion, or softening, and the temperature at which complete slagging occurs. The method requires that the feed to the sintering machine, consisting of pulverized shale or clay

TABLE 1

Preliminary Bloating Tests

Temperature (°F)	Retention Time (min.)	Observations
1900	4	no bloating
	8	" "
	12	very slight bloating
1950	4	" " "
	8	slight bloating
	12	" "
2000	4	" "
	8	moderate bloating
	12	good bloating
2050	4	moderate bloating
	8	good bloating
	12	" "
2100	4	" "
	8	good bloating, sticking
	12	" bloating, sticking

and fuel, be pelletized. The sinter cake produced has to be crushed and graded for use as aggregate. This crushed product is a harsh angular material resulting in reduced workabilities of the plastic concrete. However, it is widely used, and particularly in dry mixes, when the necessary steps are taken to overcome this difficulty.

Rotary kilns are used to fire crushed shale or clay, and occasionally pelletized or extruded clay. Two types of product are produced; one consists of clinkers of partially agglomerated material, and the other, coated particles which can be used directly in concrete. The agglomerate, of course, is similar to the sinter described above and it is necessary to crush and grade it after firing. The coated particles produced in rotary kilns is a superior aggregate for use in structural concrete. The smooth rounded surface on the particles provides greatly improved workability in plastic concrete resulting in smaller requirements of water and cement. The result is a better quality of concrete at less cost. However, it is necessary, when using the rotary kiln, to have a material with a wide bloating range, i.e., 50°F or more, and, when producing a coated particle, to size the feed to the kiln.

B. Rotary kiln process

Tests were conducted in two sizes of rotary kilns, one 5 in. x 5 ft propane fired, the other 15 in. x 15 ft oil fired. The two sizes of feed - 1/2 in. + 1/4 in., and - 1/4 in. + 6 mesh were fired in each kiln. Rate of feed was maintained at 12-lb per hr for the small kiln, and 100-lb per hr for the large kiln. In each case the temperature was maintained at the maximum possible without incurring excess sticking.

The aggregate produced in each test was crushed and screened to the following grading: 75 per cent - 3/8 in. + 4 mesh and 25 per cent - 4 + 8 mesh. The unit weight, crushing strength and bulk specific gravity of each aggregate were measured. The loose dry unit weight was measured using the shovelling procedure to fill the metal container. The crushing strength was the pressure required to give one, and two-inch compactions, to aggregate placed in a three-inch diameter cylinder to a depth of five inches.

Test conditions and results are shown in Tables 2 and 3.

TABLE 2

Rotary Kiln Tests

5" by 5' Rotary Kiln

Feed	Temperature (°F)	Retention Time (min.)	Expansion (%)	Unit Weight (lb/cu ft)	Crushing Strength (psi)		Bulk Specific Gravity S.S.D.*
					1"	2"	
-1/2"+1/4"	2000-2025	5	85	36	330	2870	1.23
-1/4"+6M	1985-2015	5	80	36	255	2080	1.28

* Saturated, surface-dry.

The expansion of the particles was perpendicular to the parting of the shale, the lumps retaining their angular shape. Loosely consolidated clusters of particles formed throughout the firing range. They were broken very easily.

TABLE 3

Rotary Kiln Tests

15" by 15' Rotary Kiln

Feed	Temperature (°F)	Retention Time (min.)	Unit Weight (lb/cu ft)	Crushing Strength (psi)		Bulk Specific Gravity S.S.D.*
				1"	2"	
-1/2"+1/4"	1980-2010	15	43	255	2120	1.35
-1/4"+6M	1980-2010	15	47	386	2260	1.44

As in the tests in the five-foot kiln, the expansion was perpendicular to the parting of the shale. Loosely consolidated clusters formed during these tests as above.

B. Sintering process

Sintering tests were conducted using the -6 mesh portion of the shale, and coal supplied. The equipment used consists of a round pot, 10-in. in diameter, with a grate at the bottom through which a draft is drawn by a connecting fan. A gas-fired igniter is used to ignite the surface of the charge. This equipment is illustrated at the end of this report. In operation, the charge is placed in the pot and ignited for a period of from one to two minutes, the flame is then withdrawn and the charge allowed to burn through to the bottom under induced draft. During this period, temperature readings are obtained at one minute intervals from thermocouples placed both in the charge near the grate and at a point immediately below the grate. The progress of burning is followed in this way and the period of time is obtained for completion of burning. A manometer is connected to the unit between the fan and pot to measure the draft at which the charges are burned.

To prepare the minus 6-mesh shale for sintering, it was crushed minus 20-mesh and pelletized in a rotating drum mixer. Minus 10-mesh coal was added as fuel in two ways; it was intimately mixed with the shale prior to pelletizing and was added to the pellets as a coating. The water required to pelletize was added in a fine spray. The pellets were screened to -3/8 in. + 8 mesh. In two of the tests a portion of the partially sintered material was mixed with the charge.

After sintering, the percentage recoveries (clinker) by weight were determined. The clinkers were crushed and screened to 75 per cent -3/8 in. + 4 mesh and 25 per cent -4 + 8 mesh. The unit weights, crushing strengths, and specific gravities, were determined on this sized product.

Test conditions and results are shown in Table 4.

The sintering tests were limited in scope and number owing to the small amount of shale sample available for the tests.

Discussion of Results

Preliminary tests in a small stationary kiln indicated the shale to have good bloating properties - both a large expansion and a workable bloating range. Additional work in the rotary kilns substantiated these findings. The small rotary kiln produced a product of lower unit weight which probably could have been duplicated in the large kiln had there been a sufficient quantity of sample on hand to make the necessary adjustments of operating conditions. However, the product from the large kiln came well within specifications for lightweight aggregates, and a quantity of expanded shale was produced from it to conduct concrete investigations which are to be described.

TABLE 4

Sintering Tests

Coal		Sinter Returned[1]	Pellet Size	Ignition		Sintering		Max. Temp (°F)	Recovery[2]	Unit Weight (lb/cu ft)	Crushing Strength, psi[3]		Sp. Gr. Bulk[4] S.S.D.
Mixed	Coated			Time in min.	Draft[5]	Time in min.	Draft[5]				1"	2"	
7.5%	5%	nil	-3/8"+4M	1 1/4	2"	19	6"	2095	47%	38	290	1690	1.17
7.5%	5%	nil	-3/8"+4M	1 1/4	2"	9	8"	2035	35%	37	330	2290	1.04
7.5%	5%	20%	-3/8"+4M	1 1/4	2"	8	6"	625	52%	33	290	1450	0.92
7.5%	5%	20%	-3/8"+4M	1 1/4	2"	13	4"	845	52%	34	320	1620	0.85

1 - Sinter returned refers to sintered fines mixed with the original pellets.

2 - Recovery - per cent clinker revovered from burned charge.

3 - In lb. per sq. in. required to crush the sized aggregate in the 3 in. cylinder.

4 - Bulk specific gravity, saturated surface-dry. (SSD)

5 - Drafts measured in inches of water.

Sufficient work was done with the sintering grate to show that a satisfactory product could also be produced by this method. Using the sintering method about 12 per cent of coal by weight of the charge was found to be adequate. The coal from the Minto field is a high-volatile fuel which is not suitable for the conventional down-draft sintering grate. The volatiles are distilled and coal tar is deposited on fans and ducts. However, sintering can now be carried out by the up-draft method, so this factor should not be critical. For our experimental purposes the down-draft laboratory equipment proved satisfactory.

CONCRETE INVESTIGATIONS

A series of concrete trial mixes were made to investigate the suitability of the Minto bloated shale product as aggregates for structural lightweight concrete, using the rotary kiln product.

Concrete Aggregate

Material was separated into coarse and fine aggregates, graded as follows:

TABLE 5

Grading of Aggregates

Coarse Aggregate		Fine Aggregate	
Passing Sieve	% Passing	Passing Sieve	% Passing
1/2 in.	100	4 mesh	100
3/8 in.	95	8 "	93
4 mesh	48	16 "	61
8 "	1	30 "	37
		50 "	22
		100 "	11

As shown by the grading, the coarse aggregate almost entirely passes the 3/8 in. sieve. The fine aggregate nearly all passes the No. 8 sieve. Eleven per cent of the fine aggregate passes the No. 100 mesh sieve and a fairly large portion of this material is dust.

Aggregate Proportions and Effect of Air-Entrainment

The shape of the bloated shale particles is rather angular and sharp. To avoid harsh concrete mixes and to improve the workability, a large proportion of fine aggregates must be used.

To establish the correct proportions, several preliminary trial mixes of different proportions were made. A ratio of 40 to 60 per cent by volume of fine to coarse aggregates, in a 6-bag plain mix, was found to be too harsh, requiring a larger amount of water, which in turn, resulted in excessive bleeding of the mixture. Addition of AEA (Air-Entraining-Agent) Darex lowered the amount of required water and eliminated the bleeding but decreased the compressive strength. In decreasing the amount of air, the workability was impaired, and the amount of the fine aggregate had to be increased to 50 per cent to attain proper workability. of the concrete mix.

It was found that 50 per cent of fine aggregate is the minimum amount, which should be used with 6 per cent air entrainment, to produce good workability for structural lightweight concrete. More fines require more water which reduces the compressive strength.

A ratio of 50:50 per cent by volume, of fine to coarse aggregates, was used in all further mixes in this investigation.

The amount of purposely entrained air was determined by the method of utilizing the differential in air content between air-entrained and non air-entrained concrete. The air content in each case was measured by Techkote air-meter with the extended pressure gauge.

Use of Admixtures in the Mixes

The grading of the bloated Minto shale aggregates shows that 11 per cent of fines passes the No. 100 mesh sieve. Because of the larger than normal proportion of these fines present, a dispersing agent (D.A. - Pozzolith) was used, which reduced the amount of water which would be otherwise necessary. As this material does not entrain enough air, an addition of a small amount of an air-entraining-agent (A.E.A.) for extra workability was made.

In all trial mixes, 0.6 oz of A.E.A. (Darex) and 1/4 lb of D.A. (Pozzolith) per bag of cement was used.

Concrete Trial Mixes

Preliminary trial mixes provided us with information on the fundamental characteristics of concrete made with Minto shale aggregates: i.e., the proper ratio of fine to coarse aggregate, the required amount of total absorption and mixing water, and the proper amount of air-entrainment for workability of the mixtures.

Five lightweight concrete test mixes with cement factors ranging from 4 to 10 bags per cubic yard of concrete were designed. Five 1/2 cu ft batches of concrete were prepared. The aggregates were presoaked in water over night and drained for one hour before use. The weights of soaked and drained aggregates were obtained before mixing was started. Specified amounts of a dispersing agent (D. A. - Pozzolith) and an air-entraining agent (A. E. A. - Darex) were prepared in a known amount of water. After cement, aggregate and admixtures were placed in the mixer, water was added sparingly to obtain a mixture with a slump of 2 ± 1/2 inches. After mixing for two min, mixer was allowed to rest for two min, then remixed for an additional two min. Seven 4 x 8 in. test cylinders were moulded from each batch -2 for 7-day and 2 each for 28-day standard moist-cured and dry-stored compressive strength tests. At the end of 7-day moist-curing period all cylinders were weighed in air and water for determination of volume values, which was used in density calculations at later ages.

Concrete mix data and characteristic, of fresh concrete mixtures are compiled in Table 6.

Test results on compressive strength and other properties of hardened lightweight concrete are compiled in Table 7.

TABLE 6

Concrete Mix Data

Mix No.	Test No.	Mix Proportions per 1 cu yd of Concrete						Mix Characteristics		
		Cement lb Bags	SSD Aggreg.*		Water lb	Admixtures		Slump in.	Entrained Air %	Unit Weight lb/cu ft
			Fine, lb	Coarse, lb		D.A. lb	A.E.A. Oz.			
1	Lw 5	345	838	779	328	1.0	2.5	1 1/2	6.0	84.8
2	Lw 8	459	786	730	315	1.3	4.0	2 1/4	6.0	84.8
3	Lw 9	590	760	709	316	1.7	4.5	2 1/4	5.5	88.0
4	Lw10	741	756	700	328	2.1	5.5	2	3.0	93.5
5	Lw11	890	735	682	353	2.5	9.0	2	1.0	98.4

*Saturated Surface-Dry Aggregate.

TABLE 7

Properties of Hardened Concrete

Mix No.	Cement, Bags per cu yd Concrete	Compr. Strength, psi			Concrete Density, lb/cu ft			Moisture, Per cent, Room-Dry Concrete	Absorpt., Per cent, Oven-Dry Concrete
		Stand. moist-cured 7-day	Stand. moist-cured 28-day	Room-dry* 28-day	Saturated, Surf.-Dry Concrete	Room-Dry* Concrete	Oven-Dry* Concrete		
1	3.95	910	1374	1425	89.6	79.0	76.3	3.6	17.6
2	5.25	1670	2002	2162	88.3	82.2	78.4	4.9	12.7
3	6.75	2426	3100	3100	91.4	87.5	83.0	5.1	10.1
4	8.45	3120	4215	4100	97.6	94.1	89.8	4.9	8.6
5	10.20	4257	5630	5180	99.9	96.7	92.2	4.8	8.4

*Room-Dry Concrete - After initial 7 days stand. moist-curing, 21 days dry storage in lab. room (about 50% R. H. and 70°F).

**Oven-Dry Concrete - After dry storage, 72 hr drying in oven at 122°F.

Mix Design for Desired Strength

Graph I, representing the mix proportions plotted against the compressive strength at 7 and 28 days age, was drawn using results obtained from the trial mixes and compiled in Table 7.

Concrete mixes for structural purposes should be designed to produce the necessary workability in the fresh concrete and to meet the specified strength of the hardened concrete.

Graph I represents concrete mixes ranging from 1000 to 5000 psi. Specifications for controlled structural concrete usually call for 20 per cent overstrength on concrete mix designs. The graph makes it possible to derive mix proportions for any strength required within the above-mentioned range.

Let us assume we wished to design a 300 psi lightweight concrete mix with 20 per cent overstrength at 28-days. From the graph we obtain the mix proportions for a 3600 psi concrete mix, which are as follows:

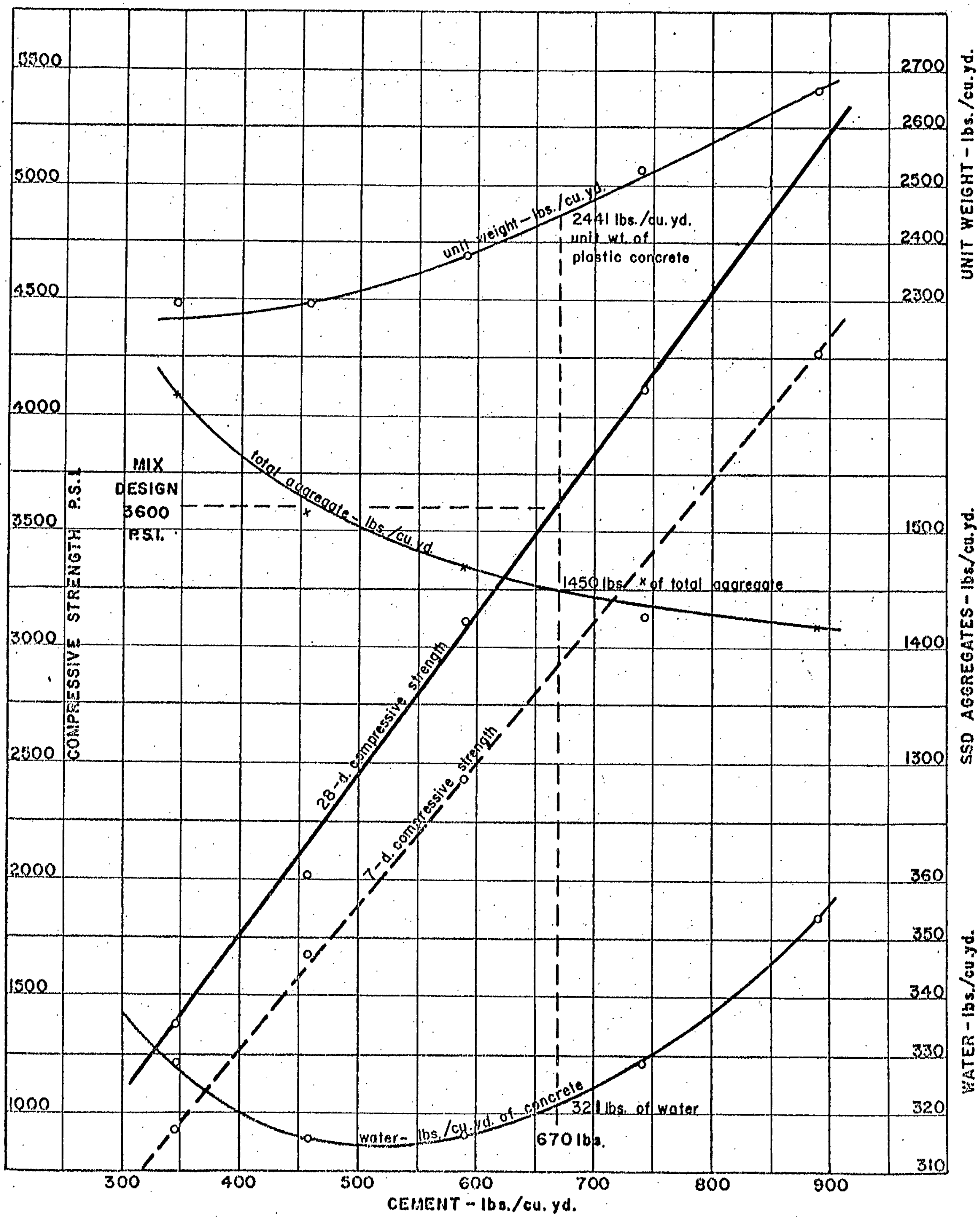
Weights for 1 cu yd of 3000 psi concrete

Cement, portland		-	670 lb
Total aggregates, SSD		-	1450 lb
Water		-	321 lb
			2441 lb
Admixtures:	Pozzolith, D. A.	-	2 lb
	Darex, A. E. A.	-	5 oz

It must be borne in mind, that this mix design is good only for a concrete made with the particular aggregates using admixtures as specified, and a slump of 2 to 3 inches.

GRAPH — I

LIGHTWEIGHT CONCRETE MIXES — MINTO EXPANDED SHALE AGGREGATES



Discussion of Results

A good workable concrete mix can be obtained with bloated Minto shale as aggregate by using a limited air-entrainment and a suitable dispersing agent. The physical qualities of the aggregate are capable of producing a high quality structural lightweight concrete.

An insufficient amount of material was available to run trial mixes for production of concrete block products. Obviously good blocks could be produced using this aggregate in a lean, dry mixture by merely reducing the amount of water to meet the consistency required for block manufacture.

GENERAL DISCUSSIONS

The choise of the process for the production of lightweight aggregate from coal mine waste shale depends on several factors.

A. Technical Factors

A rotary kiln produces "coated" lightweight aggregate that is ideally suited for strucutral concrete. A sintered aggregate, being harsh, would be more suited for concrete block manufacture. The two processes need different types of fuel; the rotary kiln requires a finely-ground coal, whereas the sintering process could use high coal-bearing shale refuse. This fuel would necessitate the use of up-draft sintering, as coal tar would be deposited on ducts and fans in down-draft sintering.

B. Economic Factors

The market demand for lightweight aggregate would affect the capacity of the plant. If a plant of a capacity 400 or more cu yd per day is required, a sintering plant should receive serious consideration. The capital costs of a sintering plant are likely to be greater than for a rotary kiln plant, but these will be amortized at a faster rate with a larger production. The rotary kiln is not as efficient with respect to fuel economy, but under the circumstances this may not be a deciding factor. Part of the increased cost of the sintering plant would result from the need for a fine-crushing and pelletizing plant.

The location of the Minto coal field with respect to the three main centres of population - Fredericton, Saint John, and Moncton, together with direct rail transportation to each city, appears to be favorable for distribution of the product.

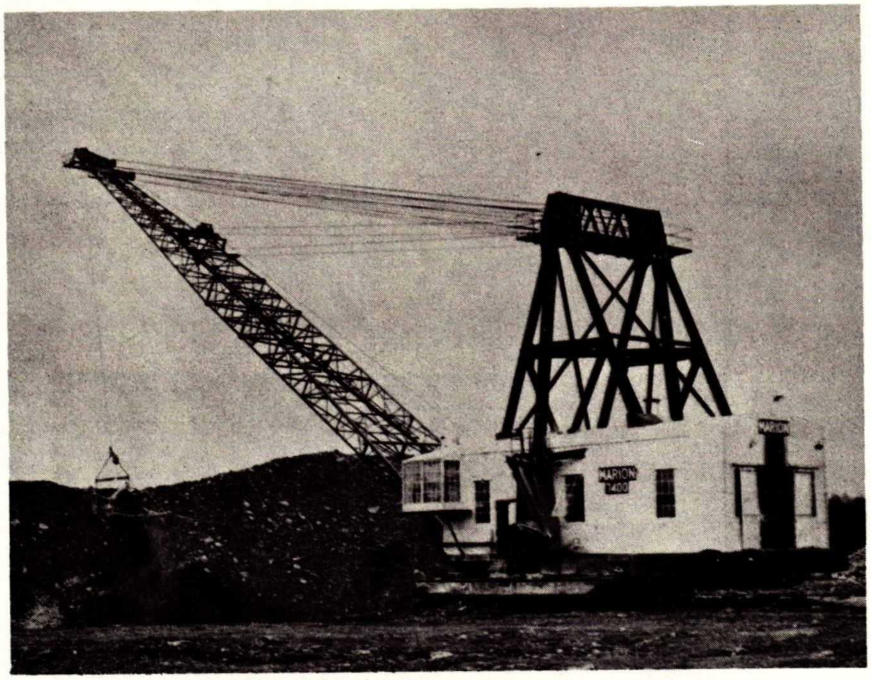
Although lightweight aggregate concrete possesses some unique properties compared to conventional concrete, a large factor in selling lightweight aggregate is the shortage of gravel and crushed stone in certain areas. If there is a scarcity of good quality conventional aggregate, lightweight aggregates are more easily accepted. On the other hand, they may have to be sold almost entirely on their superior merits of lower unit weight and improved sound and heat insulation characteristics. Structural concrete made with conventional aggregate weighs about 150 lb/cu ft, whereas lightweight aggregate concrete has a unit weight of 90 to 110 lb/cu ft. The usual 8- in concrete block made with conventional aggregate has a weight of about 44 lb. A lightweight block weighs about 25 lb. In bulk, lightweight aggregates sells at $5.00 to $6.50 cubic yard.

From the total Canadian production of lightweight aggregates, about 80 per cent is used in manufacturing of building blocks.

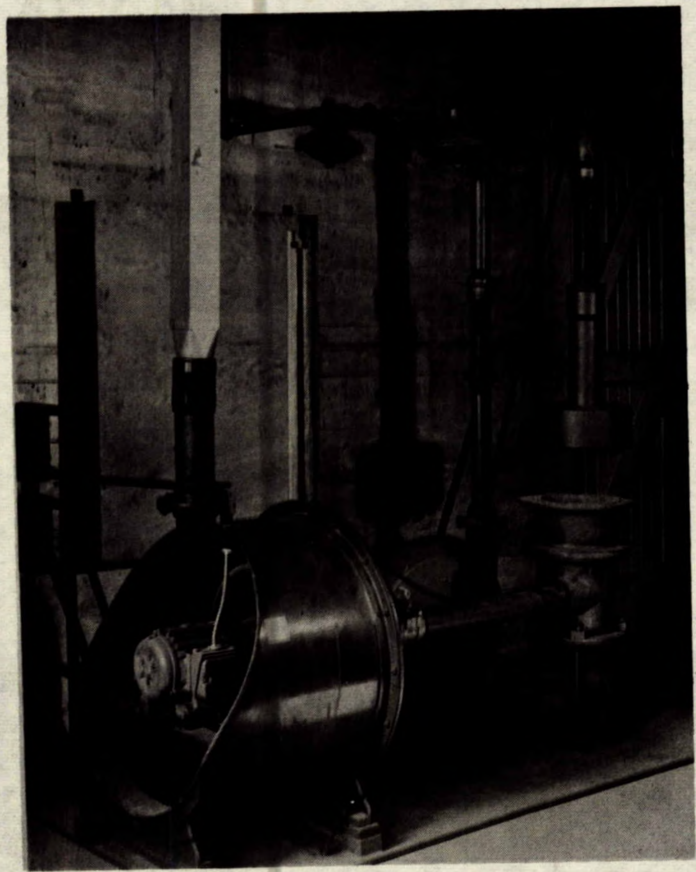
CONCLUSIONS

The waste coal-field shale, as represented by samples from Minto area in New Brunswick, is a suitable material for production of lightweight concrete aggregate by both rotary kiln bloating and sintering processes.

Concrete made with this aggregate showed physical properties required for a good structural lightweight concrete.



Avon Coal Company Limited, Minto Coal Field, New Brunswick.



Sintering Grate, Mines Branch Laboratory.

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