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SINTERED LIGHTWEIGHT AGGREGATE FROM INDIAN FLY ASHES

by **S. K. CHOPRA & KISHAN LAL***

The article reports experimental investigations carried out at the Central Building Research Institute, Roorkee on the sintering of Indian fly ashes to produce lightweight aggregate. The crushed sintered aggregate weighs about 50 *to* 60 *lb/ft*³ (0·8–0·96 *kg/lit*) *and satisfies standard requirements. Concrete prepared with this aggregate has a unit weight of* 75–87 *lb/ft*³ (1·2–1·4 *kg/lit*) *and a compressive strength range between* 1,000–3,220 *lb/in*² (71–227 *kg/cm*²). *These and other test results show that the aggregate is suitable for making masonry units as well as structural concrete.*

INDIA will shortly be producing annually about 3·5 million tons of fly ash, an industrial waste from thermal power stations using pulverized coal.[1] The use of fly ash to make sintered aggregate is particularly interesting because, not only is the problem of disposal of the ash solved, but also a new and useful material is produced.[2,3,4] Moreover, raw fly ash contains practically all the fuel required in the sintering process. Sintered pulverized fuel ash aggregate is being produced commercially in the U.S.A. and the U.K. under various trade names such as Lytag, Terlite, etc, and other countries are also becoming interested in this aggregate.[5,6,7] In view of the scope for using lightweight concrete for many purposes,[2,4] an investigation of fly ashes from existing power stations was undertaken with a view to developing a lightweight sintered aggregate. The findings of the laboratory experiments are reported in this article. A pilot sinter strand (moving grate type) is now being installed and a study of other methods of sintering is being made.

Preparation of aggregate

In the sintering of fly ash at high temperatures the cohesion of particles takes place in a state of incipient fusion and this results in the improvement of its physical and mechanical properties. The first step in the preparation of the sintered aggregate is to roll the raw fine ash into spherical pellets. This was done in an improvised pelletizer (*Fig* 1) which consists essentially of a shallow pan mounted on a rotor. The pan can be tilted to any desired angle and revolves at a speed of 20 revolutions per minute. When the ash cascades down the pan under a fine spray of water, it rolls itself into spherical pellets ($\frac{3}{8}$ to $\frac{1}{4}$ in dia) which are strong enough for subsequent handling.

The sintering of fly ash has been done mostly in a shaft kiln or on a sinter strand, but other methods also are being tried. However, in view of the lack of information relating to the chemical and mineralogical composition of ash to its behaviour on sintering by various methods and to the mechanism of combustion and sinter formation, it is always better to make a trial first on an experimental scale.[5] Kinniburgh[8,9] has studied the sintering of British fly ashes systematically. Work at the Building Research Station, U.K., shows that, though sintering in a shaft kiln results in better heat conservation, this kiln is not suitable for sintering ashes containing a wide range of unburnt fuel.[10] The sinter strand is considered better for sintering the latter type of

Fig I The first step in the preparation of the sintered aggregate is to roll the raw fine ash into spherical pellets. This was done in an improvised pelletizer consisting of a shallow pan mounted on a rotor

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TABLE I. Properties of Indian fly ashes

Source of fly ash	Specific gravity	Specific surface area, cm²/gm	Loss on ignition, per cent	Sulphuric anhydrite, SO_3, content, per cent	Alkalis
Bokaro	2·19	4,000	11·11	Trace	Trace
Kanpur	2·23	3,700	16·22	0·25	1·49
Madras	2·19	3,863	15·47	Trace	2·55

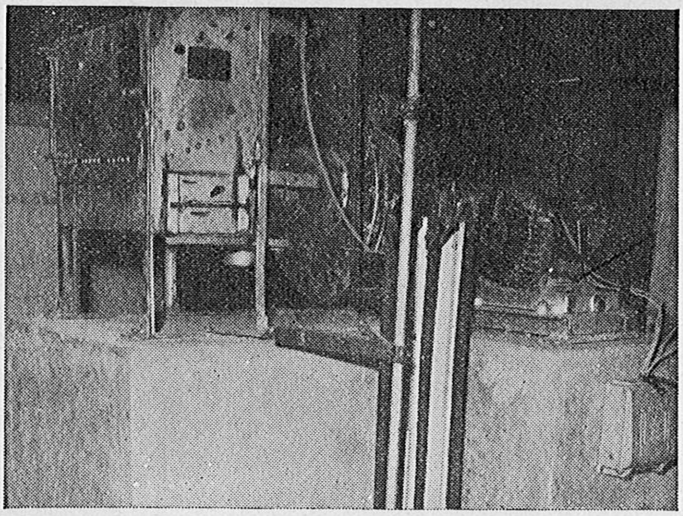

Fig 2 The pilot sintering furnace used in the investigations. An exhaust fan sucks through a bed of spherical pellets resting on an inclined grate at the bottom of the furnace, whilst an adjustable damper regulates the draught

ashes because the control of operation is easier. Since Indian ashes (*Table* 1) contain comparatively a higher content of unburnt fuel, sintering on a sinter strand was adopted.

The pilot sintering furnace used in the present investigation is shown in *Fig* 2. The capacity of the chamber is about 1 ft³ and it is fitted with an inclined grate at the bottom. A 1·5 H.P. exhaust fan sucks the combustion air through a bed of spherical pellets and an adjustable damper regulates the draught. The exhaust gases are led into the atmosphere through a chimney. The furnace chamber is charged with fly ash pellets which form a permeable bed on the grate. The top of the bed is lighted with a gas burner or alternately with a small quantity of coal spread evenly on the bed. When the bed begins to catch fire, the exhaust fan is started and produces suction so that the fire travels downwards at a suitable rate. Fly ash samples from the thermal power stations at Bokaro (Bihar), Kanpur, and Madras were tried. Of the samples collected from Bokaro, only two could be rolled into pellets. These were from the dust collector hoppers and the setting tanks, respectively. The latter were built on the bed of the river Damodar with a view to separate the finest fraction of the ash being thrown out by the Station in the form of a slurry.

The properties of fly ash which appear to influence its ability to roll itself into spherical pellets are its fineness, content of unburnt fuel, and impurities such as calcium sulphate and other salts. The amount of water required for pelletizing a fly ash can easily be controlled with the help of a fine spray nozzle. A trial on the pan reveals much more than all the other tests put together.

Both samples of the Bokaro ash could be sintered to produce a good lightweight aggregate (*Figs* 3 *and* 4). The pellets behaved well in the sintering furnace because they contain unburnt fuel just sufficient to raise the temperatures high enough to effect sintering without any 'slagging.' Some slagging was observed when sintering the samples from Kanpur and Madras. Since the latter contain a greater quantity of unburnt fuel, the control of the sintering operation was rather difficult. It remains to be seen how this type of ash behaves on a moving grate sinter strand.

Properties of the aggregates

Since the aggregates prepared from the two samples of the Bokaro ash showed little difference in their unit weights, the two lots were combined. The uncrushed spherical pellets weighed about 40 lb/ft³ (0·64 kg/lit). The unit weight of the crushed aggregate (F.M. 3·75) was found to be about 55 lb/ft³. The corresponding values for the samples from Kanpur and Madras were 54 and 58 lb/ft³, respectively.

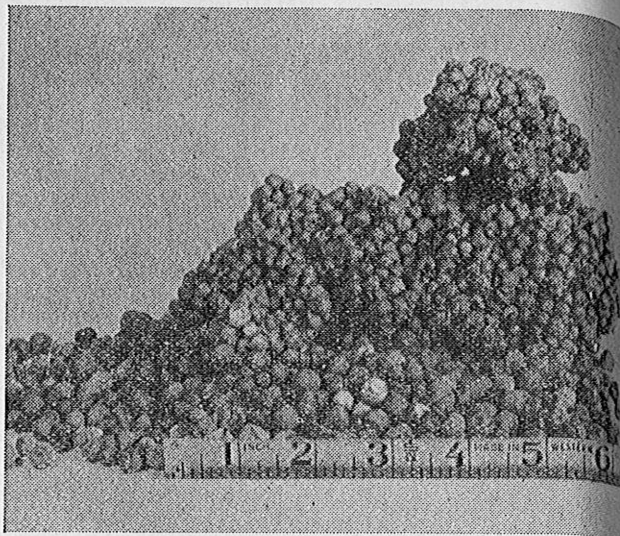

Fig 3 Showing sintered lightweight aggregate made from Bokaro fl

Sintered fly ash aggregate normally does not con deleterious materials which are generally present in fur clinker, breeze and even in raw fly ash and, if presen quantities more than specified, are known to result in failure of concrete. This is a distinct advantage with sint aggregate prepared from fly ash, and is evident from data reported in *Table* 2. The method of manufactur such that there is little likelihood of the presence of unb fuel in any appreciable quantity in the sintered produc

Sintered aggregate is strong enough for the jobs for w it is normally employed. The aggregate crushing stre (*Table* 2) was found by determining the load require produce 10 per cent fines passing a No. 14 U.S. sieve. results of the staining test, carried out as per ASTM signation C331–53T for lightweight aggregates, and w absorption of the aggregates (*Table* 2) also show the supe ity of the aggregate prepared from Bokaro fly ash.

Properties of lightweight concretes

Lightweight concrete was prepared according to the u practices.[11,12] The grading of the sintered aggregate (Fi and the quantity of mixing water were determined aft few trials. The specimens for compressive strength shrinkage tests were 4 in cubes and 2 × 2 × 10 in bea respectively. The modulus of elasticity was determined

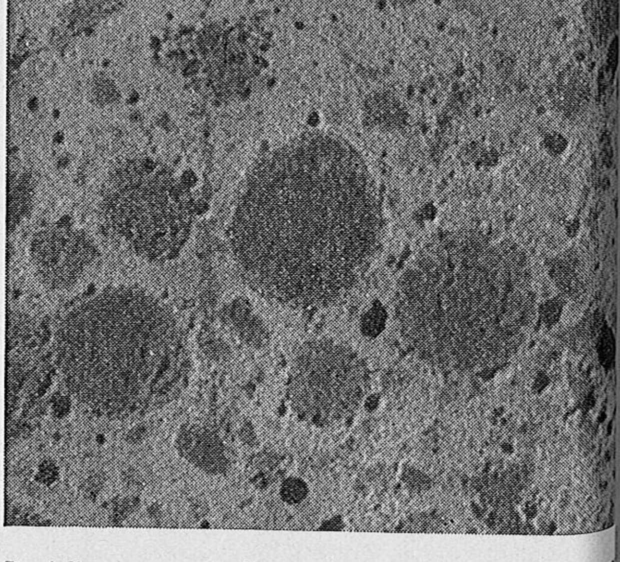

Fig 4 Showing a macrophotograph of sintered lightweight aggr embedded in concrete

TABLE 2. Properties of sintered aggregates

Aggregate	Bulk density, lb/ft³ (kg/lit)		24-hour water absorption, per cent by vol		Aggregate crushing strength, tons (kg)	Residual fuel at 750°C for 4 hours, per cent	Stain index value
	Ungraded	Graded	Ungraded	Graded			
Bokaro	40·0 (0·64)	55·0 (0·88)	19·6	49·7	5·50 (5,588)	1·02	20 (very light stain)
Kanpur	38·0 (0·608)	54·0 (0·864)	26·6	54·0	1·20 (1,219)	3·70	40 (light stain)
Madras	40·0 (0·64)	58·0 (0·928)	21·9	58·4	1·20 (1,219)	2·28	60 (moderate stain)

TABLE 3. Properties of lightweight concretes

Sintered aggregate	Mix proportions by volume cement : sand : aggregate	W/c ratio (gross)	Dry bulk density, lb/ft³ (kg/lit)	28-day compressive strength, lb/in² (kg/cm²)	28-day flexural strength, lb/in² (kg/cm²)	Modulus of elasticity (sonic), lb/in²	Drying shrinkage, per cent	
							at 28 days	at 90 days
Bokaro	1 : 0 : 4	1·07	87·0 (1·39)	3,220 (227)	545 (38)	$2 \cdot 855 \times 10^6$	0·071	0·076
	1 : 0 : 5	1·33	81·0 (1·30)	2,072 (146)	524 (37)	$2 \cdot 085 \times 10^6$	0·068	0·073
	1 : 0 : 6	1·46	77·0 (1·23)	1,750 (123)	509 (36)	$1 \cdot 867 \times 10^6$	0·051	0·057
	1 : 0 : 9	1·76	75·0 (1·20)	1,003 (71)	378 (27)	$1 \cdot 612 \times 10^6$	0·046	0·051
	1 : 1·7 : 3·3	0·96	101·0 (1·61)	3,150 (222)	—	—	0·071	0·077
	1 : 1·2 : 2·4	0·92	116·0 (1·86)	3,164 (223)	843 (59)	—	0·052	0·065
Kanpur	1 : 0 : 6	1·94	72·5 (1·16)	840 (59)	—	—	0·060	0·065
Madras	1 : 0 : 6	1·83	77·0 (1·23)	686 (48)	—	—	0·069	0·073

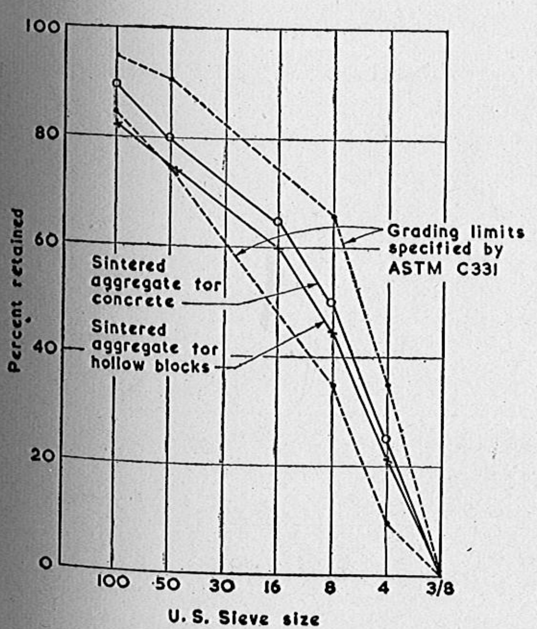

Fig 5 Grading of sintered aggregate

the sonic method on 2 × 2 × 10 in specimens. The concrete specimens were filled on a vibration table ; hand compaction is recommended for concretes with higher water contents. The specimens were cured in a humidity of at least 95 per cent and at a temperature of 27 ± 2 degrees C.

The properties of concretes prepared with the sintered aggregate from the Bokaro and other ashes are reported in *Table* 3. The unit weights and strengths of the various concrete mixes range between 75 to 87 lb/ft³ and about 1,000 to 3,220 lb/in², respectively. The relationship between density and strength is shown in *Fig* 6 and is typical of lightweight concretes. Moreover, the strengths are comparable to those reported in the literature for similar unit weights. The strengths also show that the Bokaro aggregate satisfies the standard requirements for making both masonry blocks and structural concrete.[13,14] The concretes prepared with the other two aggregates (*Table* 3) appear to be suitable only for making blocks for non-load-bearing purposes. The values of flexural strengths and modulus of elasticity and shrinkage are also reported in *Table* 3. According to ASTM Designation C331–53T for Lightweight Aggregate for Concrete Masonry Units, a 1 : 6 concrete prepared with the lightweight aggregate should not show drying shrinkage more than 0·10 per cent. The data shows that all the aggregates pass this test.

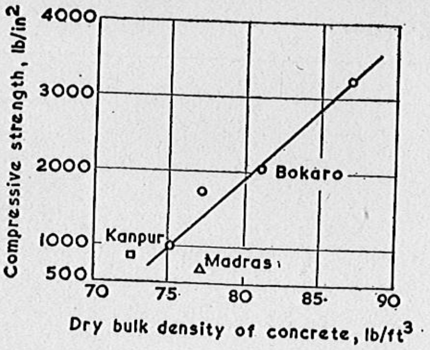

Fig 6 Relationship between bulk density and strength of sintered aggregate concrete

No-fines concretes were also prepared by using sintered aggregate ($-\frac{3}{8}$ in $+\frac{3}{16}$ in) and cement in proportions of 9 : 1 and 11 : 1 by volume. The strengths of this concrete were found to be rather low. A few solid and hollow building blocks were also prepared from a 1 : 6 mix of lightweight concrete and the test data is reported in *Table* 4. The masonry blocks have strengths much higher than those specified for use in building either load-bearing or non-load-bearing walls. The drying shrinkage of the blocks is also within the permissible limits.[13] Thermal conductivity (K) value for a 1 : 6 concrete of unit weight of 75 lb/ft³ was found to be 6·51 Btu. in/ft² hr °F at a mean temperature of 105°F.

Conclusions

The investigation shows that a sintered lightweight aggregate can be produced from Indian fly ashes and this aggregate is suitable for making lightweight concretes of strength and other properties comparable to those produced in other countries. In view of the serious problem which the disposal of fly ash poses and the profitable use which can be made of it after sintering as a lightweight aggregate, experiments are being carried out to study the relative merits of other methods of sintering.

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TABLE 4. Properties of lightweight concrete masonry bl

Type and size of block, inches (cm)	Mix proportion by volume, cement : sintered aggregate	28-day crushing strength, lb/in² (kg/cm²)	Dryi shrink per c
Hollow blocks			
17·5 × 8 × 4·5 (44·45 × 20·32 × 11·43)	1 : 6	703 (50·0)	0·04
17·5 × 8 × 8·5 (44·45 × 20·32 × 21·59)	1 : 6	1,047 (74·0)	0·04
Solid block			
20 × 10 × 4 (50·8 × 25·4 × 10·16)	1 : 6	1,525 (107·0)	0·04

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