Bloated clay: an unconventional artificial lightweight aggregate

Kishan Lal, Ranbir Singh and V. G. Upadhyaya

The paper discusses the properties of bloated clay aggregates produced in a pilot 20-tonne/day rotary kiln, and the structural properties of commonly used lightweight concrete compositions. In view of its technical and economic advantages the use of bloated clay aggregate is strongly recommended in places where the cost of crushed stone aggregate is high, and suitable clays, especially silts from waterworks, are easily available.

Bloated or expanded clays and shales are all-purpose lightweight aggregates which have been known since 1917. They are being produced and used increasingly in many developed countries under various trade names. In this country the Central Building Research Institute has been working on the development of bloated clay aggregate and lightweight concrete from 1961 onwards[1].

The use of lightweight aggregate for making concrete in place of natural sand and crushed stone aggregate makes it possible to produce concretes of the same strength as normal concrete but weighing only about two-thirds of, or even less than, the weight of the latter. The use of lightweight concrete in building construction results in many direct and indirect advantages.

Engineers, architects, and builders are now becoming increasingly aware of the present-day trend of using lighter building components with better thermal and acoustic properties. A reduction of thirty-five to forty per cent in the dead load of buildings can be easily achieved with resultant savings of 22 to 24 per cent in reinforcing steel and the cost of foundations, etc[2]. The increase in the speed of construction obtained by using precast lightweight concrete components has also attracted the attention of the builders. Lightweight bloated clay aggregate concretes find application practically for all civil engineering works for which conventional concrete is used, such as for example :

(*i*) cast in situ work for the construction of buildings, roads and bridges, etc

(*ii*) production of precast beams, medium- and large-size wall panels, flooring and roofing units of different types, and other structural members

(*iii*) production of masonry blocks, both solid and hollow, for load-bearing and non-load-bearing constructions.

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A 20-tonne/day rotary kiln has been set up in the premises of the Central Building Research Institute. This has been successfully used for producing bloated clay aggregate from local clay and silts obtained from the Varanasi, Kanpur and Palta waterworks[3]. In this paper the lightweight aggregates produced from different clays have been evaluated for making structural grade concrete and also for lean concrete for producing masonry blocks. The economics of this material is also discussed.

Properties of bloated clay aggregate

Bloated clay aggregate produced in the rotary kiln is a spherical-shaped, hard, light and porous material. It has a dark brown to greyish black colour. The individual particles have a hard shell on the outer periphery and a porous structure inside. The size of the particles ranges from 5mm to 20mm. The properties of the bloated clay aggregates produced from different clays and used in this study are given in *Table* 1. The bulk densities and the water-absorption values of the aggregates were determined in accordance with the procedures described in the Indian Standard Methods of Test for Aggregates for Concrete, IS : 2386 (Part III)–1963. The ten per cent fines value of the aggregate was determined in accordance with the procedure specified in the Indian Standard Methods of Test for Aggregates for Concrete,

TABLE 1 Properties of bloated clay aggregates and natural sand

Source of clays or silts for the aggregate	*Bulk density of aggregate made up of 50 per cent of material between 9·5-mm to 12·5-mm, and 50 per cent of material between 4·75-mm to 9·5-mm,* kg/m³	*Ten per cent fines value,* tonnes	*Water absorption,* per cent by weight	*Bulk density of fine aggregate,* kg/m³	*Fineness modulus of fine aggregate*
Roorkee	880	5·0	8·3	739	3·17
Varanasi	588	5·0	11·4	669	2·60
Palta	648	7·0	19·0	712	2·68
Kanpur	774	6·1	9·3	810	2·55
Mixed sand containing 50 per cent Badarpur sand and 50 per cent Solani sand				1392 to 1485	1·17 to 1·40

ing materials were used :

(*i*) ordinary Portland cement conforming to IS : 269-1967

(*ii*) bloated clay coarse aggregate having a particle size range of 4·75mm to 12·5mm

(*iii*) bloated clay fine aggregate passing a 4·75-mm IS sieve, obtained by crushing the large size product

(*iv*) blended natural sand, produced by mixing coarse and fine sands

(*v*) water of a quality fit for drinking.

Grading of the aggregates — coarse aggregate : The bloated clay coarse aggregate was graded into two size fractions, namely, 4·75mm to 9·5mm, and 9·5mm to 12·5mm. The two fractions were mixed in equal parts by weight to produce the desired quantity of coarse aggregate for making lightweight concrete.

Bloated clay fine aggregate : The grading of the fine aggregate produced by crushing the large size product was within the limits of grading zone L1 specified in the British Standard Specification for Lightweight Aggregate for Concrete, BS 3797 : 1964, and is shown in *Fig* 1.

Natural sand : Badarpur sand was mixed with Solani sand in equal volumes to produce a medium grade blend. The grading of the blended sand, having a fineness modulus 1·27 to 1·4 which was used in the investigation, is shown in *Fig* 2.

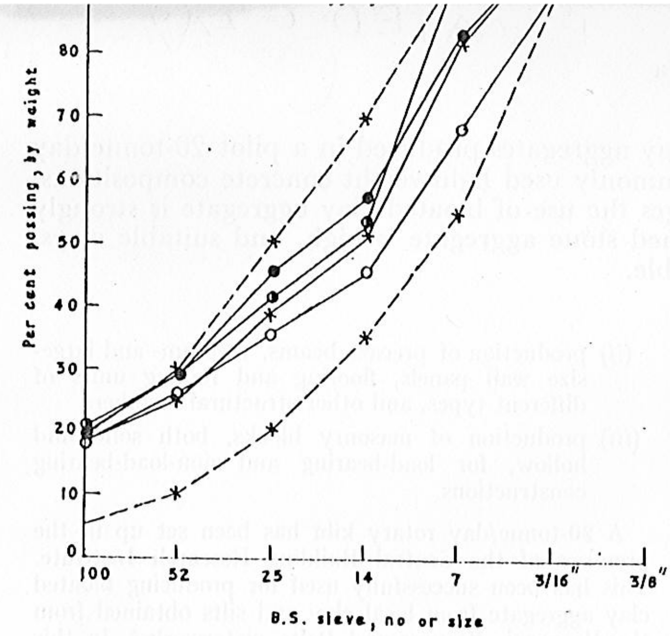

Fig 1 Grading curve for lightweight bloated clay fine aggregate

IS: 2386 (Part IV)-1963. It gives a measure of the resistance of the aggregate to crushing, and it is expressed as the load required to produce 10 per cent fines passing a 2·36-mm Indian Standard sieve.

Lightweight aggregate concrete

Lightweight aggregate concrete is produced in the same way as conventional concrete. The crushed stone aggregate and sand of conventional concrete are replaced by artificial lightweight coarse and fine aggregates. In many

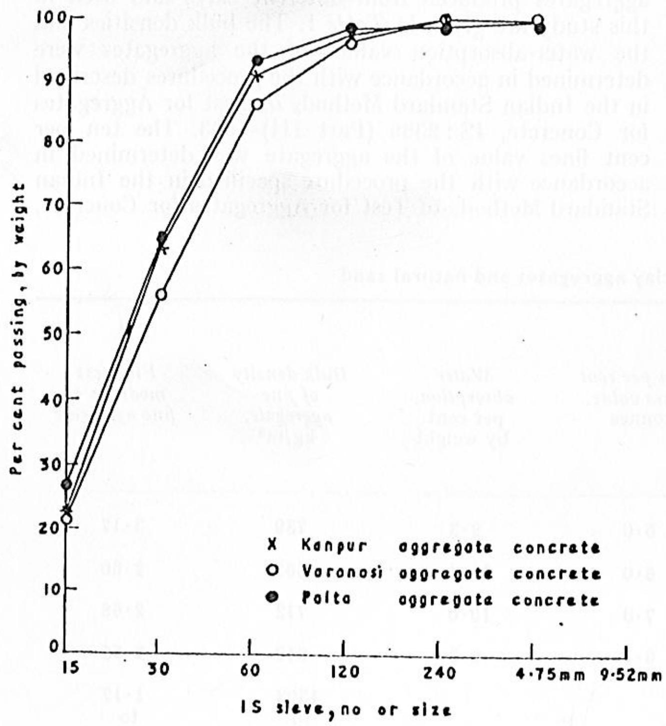

Fig 2 Graph showing grading of natural sand used

Preparation of lightweight concrete test specimens

Concrete mixes : The lightweight concrete mixes were made in two series. In the first series bloated clay coarse and fine aggregates, that is, all lightweight aggregates, were used, while in the second series sand was used instead of lightweight fines. The proportion of coarse to fine aggregate was 2 : 1 by volume. The exact proportions and quantities of cement, fine and coarse aggregates, and the total water-cement ratio used to maintain uniform workability, with a compacting factor of 0·8 are shown in *Tables* 2 and 3.

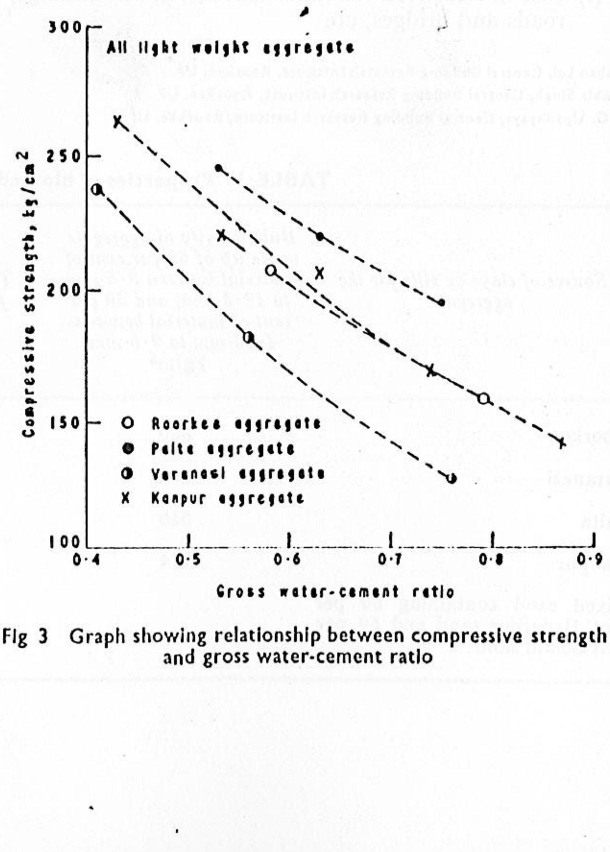

Fig 3 Graph showing relationship between compressive strength and gross water-cement ratio

number		aggregate	aggregate				
			Roorkee				
R1	1	2·0	4·0	305	1540	0·70	0·82
R2	1	1·3	2·67	415	1592	0·58	0·80
			Varanasi				
V1	1	2·4	3·6	300	1300	0·76	0·81
V2	1	1·6	2·4	416	1365	0·56	0·81
V3	1	0·8	1·2	666	1510	0·41	0·76
			Palta				
P1	1	2·0	3·0	327	1305	0·75	0·80
P2	1	1·6	2·4	403	1413	0·63	0·80
P3	1	1·0	2·0	520	1518	0·53	0·81
			Kanpur				
K1	1	2·4	3·6	305	1466	0·87	0·81
K2	1	2·0	3·0	320	1471	0·74	0·81
K3	1	1·6	2·4	399	1521	0·63	0·81
K4	1	1·2	1·8	488	1546	0·53	0·81
K5	1	0·8	1·2	654	1640	0·43	0·80
			Dense conventional concrete				
	cement	sand	gravel				
DC1	1	2·0	4·0	294	2332	0·58	0·85

TABLE 3 Composition and properties of fresh lightweight concrete using lightweight coarse aggregate and natural sand (series 2)

Aggregate	Mix proportions by volume: cement	natural sand lightweight	coarse aggregate	Cement content, kg/m³	Density of fresh concrete, kg/m³	Water-cement ratio	Compacting factor
			Roorkee				
RS1	1	2·00	4·00	310	1850	0·67	0·81
RS2	1	1·67	3·33	361	1865	0·59	0·80
RS3	1	1·33	2·67	427	1885	0·51	0·80
RS4	1	1·00	2·00	531	1920	0·43	0·80
RS5	1	0·67	1·33	698	1972	0·37	0·80
			Varanasi				
VS1	1	2·00	4·00	285	1521	0·66	0·81
VS2	1	1·33	2·67	402	1586	0·51	0·81
VS3	1	0·67	1·33	652	1689	0·37	0·77
			Palta				
PS1	1	1·67	3·33	349	1703	0·68	0·80
PS2	1	1·33	2·67	420	1739	0·59	0·80
PS3	1	1·00	2·00	509	1757	0·53	0·81
			Kanpur				
KS1	1	2·00	4·00	301	1760	0·69	0·81
KS2	1	1·67	3·33	348	1777	0·62	0·82
KS3	1	1·33	2·67	416	1794	0·52	0·82
KS4	1	1·00	2·00	513	1810	0·44	0·79
KS5	1	0·67	1·33	668	1848	0·37	0·77

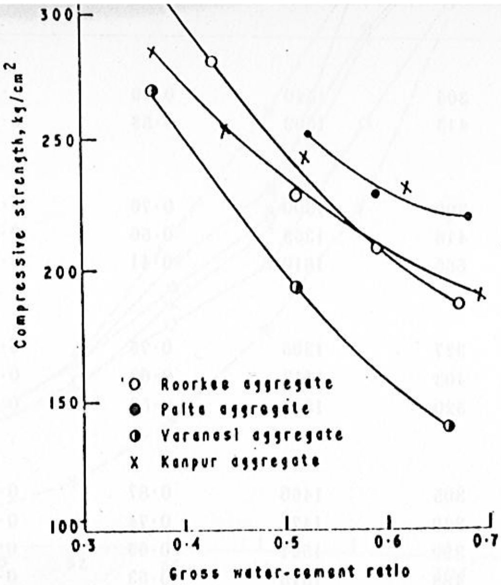

Fig 4 Graph showing relationship between compressive strength and gross water-cement ratio

Water-cement ratio : The total water-cement ratio used ranged from 0·37 to 0·87 by weight ; it varied with the cement content of the concrete mix. The values are high due to the absorptive nature of the aggregates. The relationship between the 28-day compressive strength of lightweight concrete and the total water-cement ratio is shown in *Figs* 3 and 4. The nature of the curves is quite similar to the one for conventional concrete. Similar relationship is exhibited between the cement content and the total water-cement ratio to attain the same workability, with a compacting factor of 0·8 to 0·81, *Fig* 5.

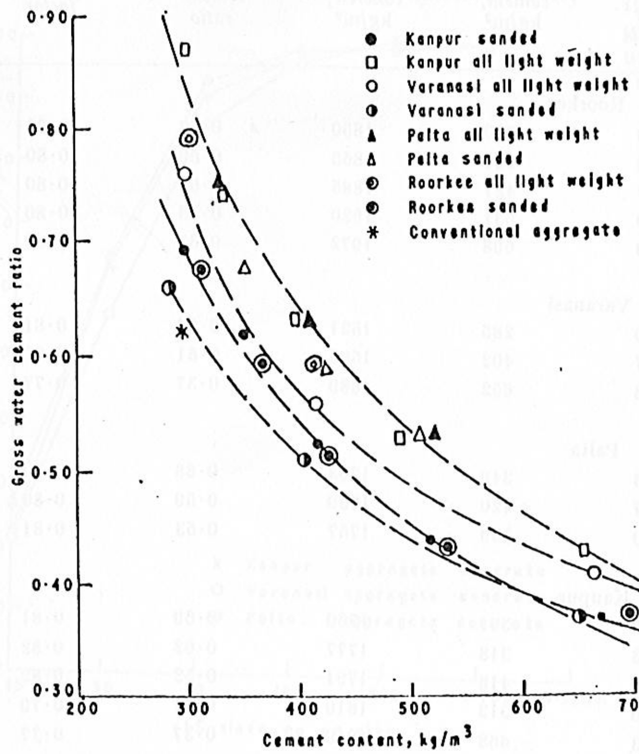

Fig 5 Relationship between cement content and gross water-cement ratio to produce same workability

the moistened aggregate, and mixed for a while, and then the remaining quantity of water was added and the materials mixed thoroughly, until the concrete was homogeneous and of uniform quality, with a compacting factor of 0·8. Test specimens were prepared as follows : (*i*) 10-cm cubes for determining bulk density, water absorption, compressive strength and bond strength ; (*ii*) 10cm × 10cm × 50cm beams for determining the flexural strength and modulus of elasticity ; and (*iii*) 5cm × 5cm × 25cm beams for determining drying shrinkage. The specimens were compacted by using a vibrating table ; they were cured by covering with wet gunny bags for the first twenty-four hours, and later by immersion in water until the time of testing in the standard manner.

Properties of lightweight concrete

Bulk density : The bulk density of fresh concrete was determined immediately after mixing ; it ranged between 1300 to 1650kg/m³ for concrete mixes of the first series (all lightweight), and 1521 to 1972kg/m³ for concrete mixes of the second series. The bulk density of oven-dried concrete was determined on 10-cm cubes ; it ranged from 1173 to 1526kg/m³ for concretes of the first series, and 1395 to 1940kg/m³ for concretes of the second series. The variation of bulk density with cement content of the concrete mixes is illustrated in *Fig* 6.

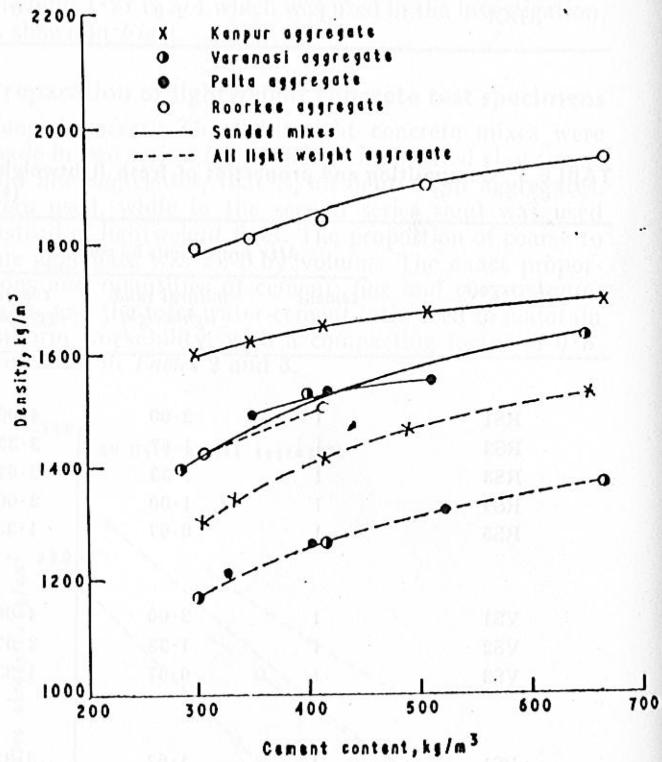

Fig 6 Variation of oven-dry concrete density versus cement content

Water absorption : The water absorption of lightweight concrete after immersion in water for twenty-four hours ranges from 6·5 to 13·8 per cent, whereas for conventional concrete of 1 : 2 : 4 mix it is about 4·5 per cent.

Compressive strength : The 7-day and 28-day compressive strengths of concretes of the first series ranged from 88 to 202kg/cm², and 127 to 264kg/cm² respectively, and for concretes of the second series, they ranged from

Bond strength : The bond strength between lightweight concrete and 12-mm diameter plain mild steel bar was determined by the pull-out test described in the Indian Standard Methods of Testing Bond in Reinforced Concrete, Part I, Pull-out Test, IS : 2770 (Part I)–1967. It was found to increase with increase in the cement content of the concrete mix, and ranged from 26 to 62kg/cm², *Tables* 4 and 5. The relationship between the bond strength and cement content is shown in *Figs* 8 and 9. The bond strength of lightweight concrete is higher than that of conventional concrete of equal compressive strength, because of the higher cement content which influences the properties of the matrix.

Flexural strength : The flexural strength of lightweight concrete was tested on 10 × 10 × 50-cm beam applying central loading. The flexural strength of bloated clay aggregate concrete was about 20 to 25 per cent of its compressive strength. The relationship between the compressive strength and the flexural strength of bloated clay lightweight-aggregate concrete is shown in *Fig* 10. This relationship seems to follow the equation $F_b = K\sqrt{F_c}$ where K is a constant, F_b is the flexural strength, and F_c is the 28-day compressive strength. For conventional concrete the value of the factor ranged between 1·6 and 2·7 while for lightweight concrete the observed values of this factor ranged between 2·62 and 3·57[4].

Modulus of elasticity : The dynamic modulus of elasticity was determined on 10 × 10 × 50-cm beams by an ultrasonic method. Values of E ranged from $1{\cdot}39$ to $2{\cdot}95 \times 10^5$ kg/cm² against $4{\cdot}29 \times 10^5$ kg/cm² for normal concrete, *Tables* 4 and 5. Bloated clay aggregate concretes showed values of modulus of elasticity of about 32 to 68 per cent of that of normal concrete having the same compressive strength. Lightweight concrete mixes containing natural sand as fine aggregate gave higher modulus of elasticity than all-lightweight aggregate concretes of equal compressive strength. The relationship between modulus of elasticity and compressive strength is shown in *Fig* 11.

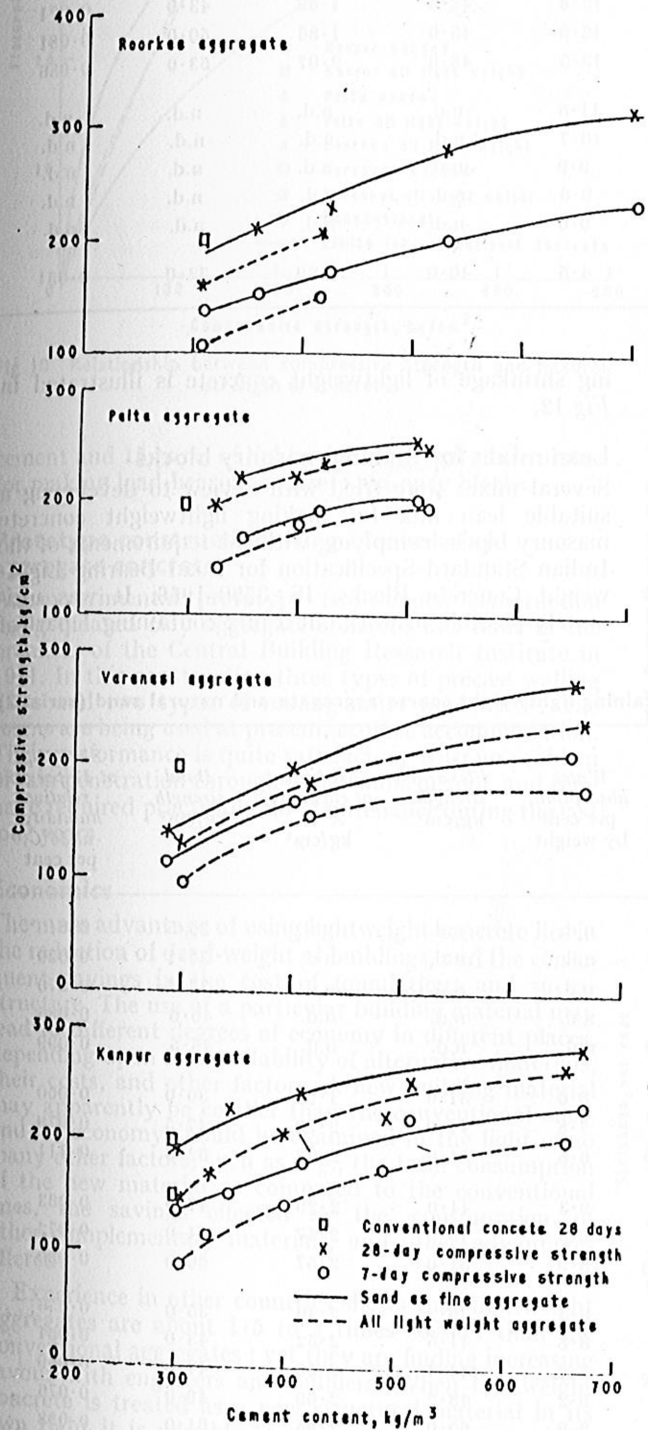

Fig 7 Relationship between cement content and compressive strength of bloated clay aggregate concretes

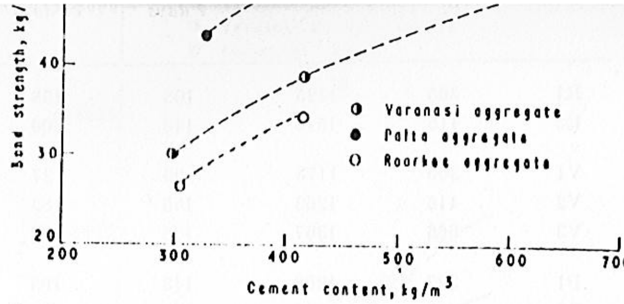

Fig 8 Relationship between cement content and bond strength of lightweight concretes (series 1) with 1·2-cm diameter plain mild steel bars

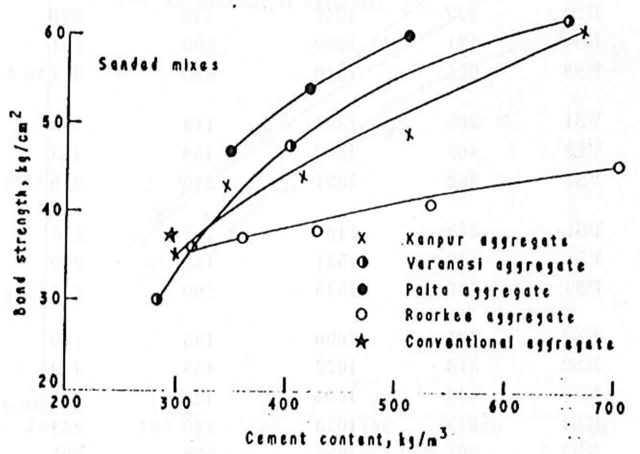

Fig 9 Relationship between cement content and bond strength of lightweight concretes (series 2) with 1·2-cm diameter plain mild steel bars

TABLE 4 Properties of hardened lightweight concrete containing lightweight coarse and fine aggregates (series 1)

Mix no	*Cement content,* kg/m³	*Oven-dry density,* kg/m³	*Compressive strength,* kg/cm² 7 days	28 days	*Water absorption,* per cent by weight	*Flexural strength,* kg/cm²	*Modulus of elasticity* × 10⁵, kg/cm²	*Bond strength,* kg/cm²	*Shrinkage at 17 per cent relative humidity at 50°C,* per cent
R1	305	1425	103	158	12·0	35·4	1·64	26·6	0·065
R2	415	1510	148	206	10·5	40·8	1·72	34·2	0·081
V1	300	1173	96	127	12·5	31·8	1·39	29·7	0·064
V2	416	1262	155	182	10·8	38·7	1·57	38·5	0·084
V3	666	1367	178	237	10·6	50·0	1·64	49·8	0·121
P1	327	1208	143	195	13·8	42·5	1·69	43·0	0·071
P2	403	1257	155	220	12·6	45·0	1·86	50·0	0·081
P3	520	1316	193	245	13·5	48·0	2·07	53·0	0·086
K1	305	1302	88	142	11·6	n.d.	n.d.	n.d.	n.d.
K2	320	1343	114	169	10·7	n.d.	n.d.	n.d.	n.d.
K3	399	1409	143	207	9·9	n.d.	n.d.	n.d.	n.d.
K4	488	1464	174	220	9·6	n.d.	n.d.	n.d.	n.d.
K5	654	1526	202	264	9·0	n.d.	n.d.	n.d.	n.d.
DC1	294	2320	135	198	4·5	40·0	4·29	32·0	0·051

Drying shrinkage : The drying shrinkage was determined on 28-day old samples at 50°C and 17 per cent relative humidity ; it increased with an increase in cement content as usual. The drying shrinkage of a lightweight concrete containing 300kg of cement per m³ was 0·049 to 0·065 per cent as compared to 0·051 for that of normal concrete having the same cement content. Rich concrete mixes with 650kg or more of cement per m³ showed ultimate shrinkage of the order of 0·12 per cent. The relationship between cement content and drying shrinkage of lightweight concrete is illustrated in *Fig* 12.

Lean mixes for making masonry blocks

Several mixes were tried with a view to developing a suitable lean mix for making lightweight concrete masonry blocks complying with the requirements of the Indian Standard Specification for Load Bearing Lightweight Concrete Blocks, IS : 3590–1966. It was ultimately possible to work out a mix containing 1 part of

TABLE 5 Properties of hardened lightweight concrete containing lightweight coarse aggregate and natural sand (series 2)

Mix no	*Cement content,* kg/m³	*Oven-dry density,* kg/m³	*Compressive strength,* kg/cm² 7 days	28 days	*Water absorption,* per cent by weight	*Flexural strength,* kg/cm²	*Modulus of elasticity,* × 10, kg/cm²	*Bond strength,* kg/cm²	*Shrinkage at 17 per cent relative humidity at 50°C,* per cent
RS1	310	1787	136	186	n.d.	n.d.	n.d.	35·5	0·049*
RS2	361	1806	151	208	n.d.	n.d.	n.d.	37·1	0·059
RS3	427	1842	170	229	n.d.	n.d.	n.d.	37·7	0·070
RS4	531	1900	200	281	n.d.	n.d.	n.d.	40·6	0·085
RS5	698	1940	230	311	n.d.	n.d.	n.d.	45·5	0·099
VS1	285	1395	113	140	8·6	31·0	1·96	30·0	0·060
VS2	402	1532	168	193	7·8	44·0	2·29	47·5	0·079
VS3	652	1631	210	269	6·5	54·0	2·67	62·0	0·111
PS1	349	1491	167	220	9·3	44·0	2·29	47·0	0·063
PS2	420	1531	188	229	9·5	49·0	2·47	54·0	0·072
PS3	509	1545	200	251	8·9	51·0	2·57	60·0	0·080
KS1	301	1600	135	189	8·1	39·2	2·40	35·0	0·055
KS2	348	1622	153	229	8·8	41·5	2·52	43·0	0·061
KS3	416	1654	180	242	8·6	44·4	2·56	44·0	0·069
KS4	513	1673	220	254	9·2	48·2	2·69	49·0	0·076
KS5	668	1695	233	285	9·9	60·0	2·95	61·0	0·098

* *Note :* This set was subjected to a relative humidity of 50 per cent at 27°C for 100 days.

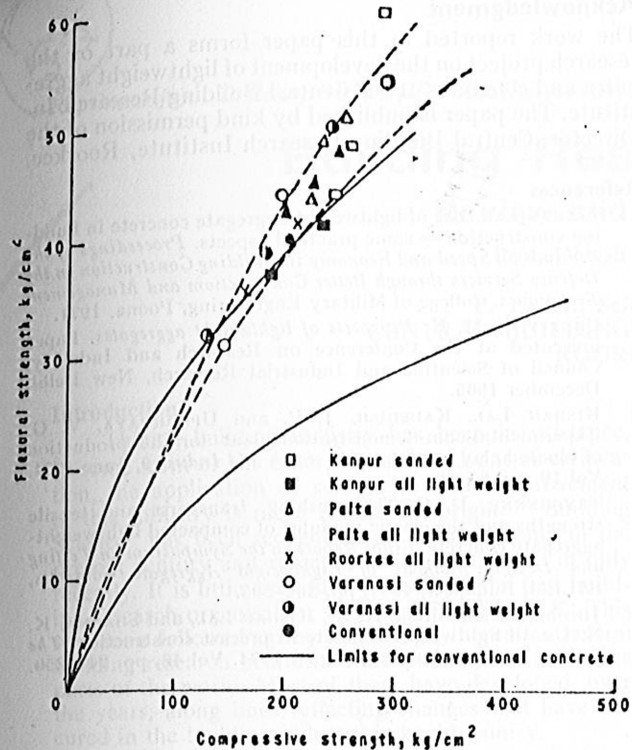

Fig 10 Relationship between compressive strength and flexural strength of concrete

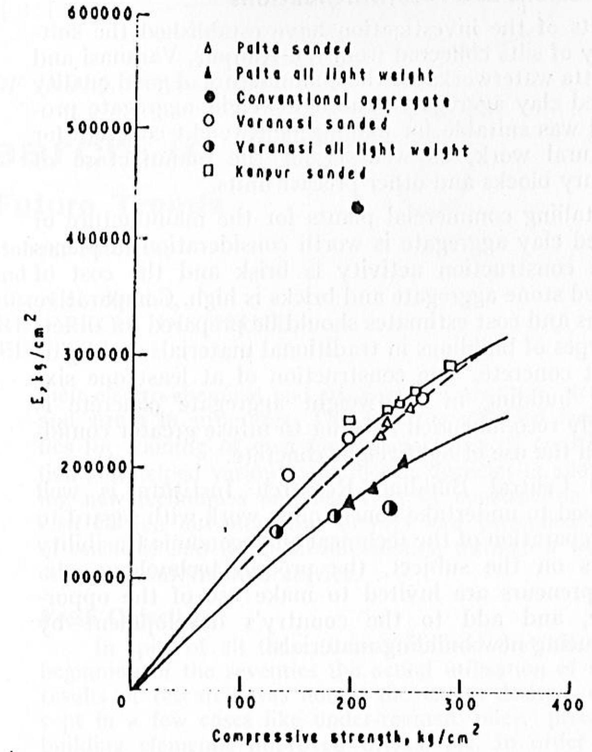

Fig 11 Relationship between compressive strength and modulus of elasticity of concrete

cement and 15 parts of lightweight aggregate by volume for making load-bearing concrete masonry blocks.

Prototype construction using bloated clay aggregate concrete

An experimental prototype two-roomed construction using bloated clay aggregate concrete was built in the premises of the Central Building Research Institute in 1971. In this construction three types of precast walling units and two types of roofing units were used[5]. The rooms are being used at present as office accommodation. Their performance is quite satisfactory with no problem of rain penetration through either walls or roof, and they have required practically no maintenance during the last four years.

Economics

The main advantage of using lightweight concrete lies in the reduction of dead-weight of buildings, and the consequent savings in the cost of foundations and superstructure. The use of a particular building material may lead to different degrees of economy in different places, depending upon the availability of alternative materials, their costs, and other factors. A new building material may apparently be costlier than the conventional ones, and its economy should be examined in the light of so many other factors, such as, *e.g.*, the total consumption of the new material as compared to the conventional ones, the savings effected in the consumption of other complementary materials, and other advantages offered.

Experience in other countries shows that lightweight aggregates are about 1·5 to 2 times costlier than the conventional aggregates ; yet they are finding increasing favour with engineers and builders. When lightweight concrete is treated as a new structural material in its own right it is possible to achieve overall economy in building construction, particularly so in multistorey buildings.

In this country, the situation may be somewhat different ; in places such as Varanasi, Lucknow, Kanpur, Calcutta and other towns situated in the plains conventional crushed stone aggregate is costly due to the need for haulage over long distances. Thus lightweight aggregates can compete very well in the matter of cost with traditional materials. The estimated selling price of bloated clay aggregate is Rs 75 to Rs 105 per m³ depending upon the bulk density of the aggregate, while crushed stone aggregate is sold for Rs 85 to Rs 100 per m³.

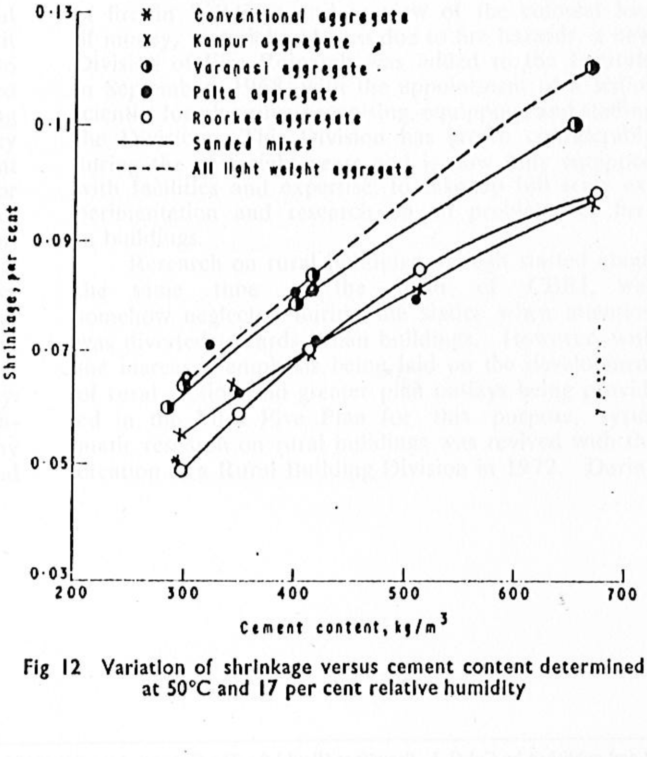

Fig 12 Variation of shrinkage versus cement content determined at 50°C and 17 per cent relative humidity

Conclusions and recommendations

Results of the investigation have established the suitability of silts collected from the Kanpur, Varanasi and Calcutta waterworks for the manufacture of good quality bloated clay aggregate. The lightweight aggregate produced was suitable for making lightweight concrete for structural work, as well as for the manufacture of masonry blocks and other precast units.

Installing commercial plants for the manufacture of bloated clay aggregate is worth consideration in places where construction activity is brisk and the cost of crushed stone aggregate and bricks is high. Comparative designs and cost estimates should be prepared for different types of buildings in traditional materials and lightweight concrete. The construction of at least one six-storey building in lightweight aggregate concrete is strongly recommended in order to infuse greater confidence in the use of lightweight concrete.

The Central Building Research Institute is well equipped to undertake consultancy work with regard to the preparation of the technical and economic feasibility reports on the subject, the process technology, etc. Entrepreneurs are invited to make use of the opportunity, and add to the country's development by introducing new building materials.

Acknowledgment

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