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Laterite as aggregate in mortar and concrete

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Laterite is a highly weathered rock and is abundantly available in coastal regions of India. Cut laterite blocks are very widely used as walling materials. During quarrying and dressing of laterite blocks a lot of material is obtained as a waste. The present study indicates that this waste may be used as fine and coarse aggregates in mortar and concrete. The relationship between specific gravity and iron content, reduction in alkalinity and silica plus alumina content, impact value and iron content of laterite aggregate have been studied and reported in this paper. It has been found that, in general, from Goa to Trivandrum, the hardness of laterite decreases. The durability study of concrete cubes made from laterite aggregates indicates that such concrete is durable against wetting and drying.

Laterite is a highly weathered material rich in secondary oxides of iron and aluminium or both. It is devoid of bases and primary silicates but may contain large amounts of quartz and kaolinite. It is either hard or capable of hardening on exposure to atmosphere[1]. Concretionary laterite rocks are readily available in many areas of tropical and subtropical regions where natural rocks and aggregates are sometimes not economically available. In India, in most of the laterite-bearing areas, laterite blocks are cut from the rock at the quarry and are used as main walling material. However, this form of construction is time-consuming and needs skilled labour. During quarrying of laterite and cutting of blocks into desired shapes, a lot of material is produced in the form of small boulders and fines, which is considered as a waste material. This waste material has not been used much in making mortar or concrete due to fear about its soundness and other properties[2, 3, 4, 5]. Several workers have studied the suitability of laterite aggregate for roads[6,7,8,9]. There are various grades of laterite rocks, some are satisfactory and some are very inferior. There are some in which practically all the particles above the sand size are very concretionary ferruginous nodules, and some in which the coarse particles are a mixture of nodules and quartzitic gravel in highly variable proportions. Some of the concretionary particles are hard while others are friable and weak.

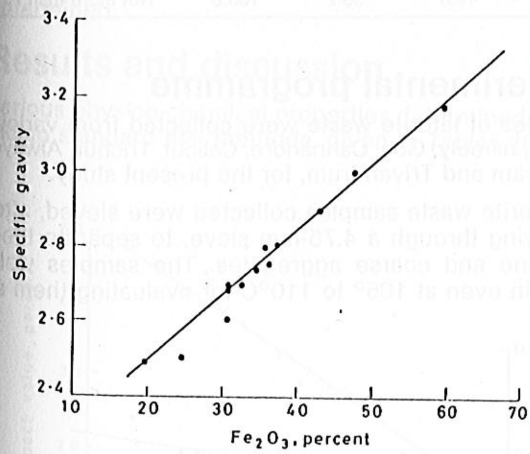

Fig 1 Relationship between Fe_2O_3 content and specific gravity of laterites

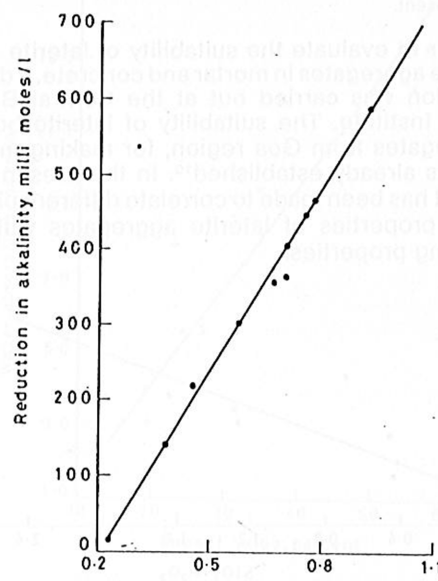

Fig 2 Relationship between $SiO_2 + Al_2O_3$ and reduction in alkalinity of laterites

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TABLE 1(*a*) Physico-chemical properties of laterite aggregates

Sr. No.	Properties	Goa G_1	Goa G_2	Goa G_3	Cannanore Can_1	Cannanore Can_2	Calicut C_1	Calicut C_2	Kottayam K
1.	Fineness modulus	2.61	2.47	2.97	3.25	3.08	2.87	3.10	2.59
2.	Specific gravity	3.05	3.18	3.00	2.74	2.89	2.88	2.75	2.49
3.	Bulk density, kg/l	1.47	1.51	1.48	1.25	1.40	1.33	1.30	1.25
4.	Water absorption, percent	4.0	3.3	5.5	8.0	8.2	9.5	10.2	11.1
5.	Deleterious matter								
	(*i*) Clay + silt, percent	11.4	10.4	9.5	12.4	11.8	13.3	11.1	12.0
	(*ii*) Clay, percent	1.2	2.0	1.0	1.3	0.8	0.5	1.4	1.6
	(*iii*) Material passing 75-micron, percent	8.5	8.9	8.0	8.6	8.1	4.3	4.0	6.0
6.	Organic impurities	A	A	A	A	A	A	A	A
7.	Soundness, percent loss	6.2	8.4	3.4	39.9	31.7	26.2	28.9	42.3
8.	Alkali-aggregate reactivity								
	Rc, millimoles/l	134.4	142.8	42.72	336.0	304.5	515.0	357.0	138.6
	Sc, millimoles/l	—	—	0.90	30.6	26.5	54.6	42.3	6.4

Note: A = absent.

TABLE 1(*b*) Physico-chemical properties of laterite aggregates

Sr. No.	Properties	Trichur T_1	Trichur T_2	Trichur T_3	Trivandrum Tr_1	Trivandrum Tr_2	Trivandrum Tr_3	Alwaye A	IS limit
1.	Fineness modulus	2.88	2.78	2.80	2.15	2.56	3.28	2.76	—
2.	Specific gravity	2.60	2.72	2.40	2.48	2.28	2.68	2.35	—
3.	Bulk density, kg/l	1.40	1.32	1.05	1.23	1.20	1.61	1.31	—
4.	Water absorption, percent	7.5	9.5	12.2	8.3	13.3	5.5	9.0	Not more than 5
5.	Deleterious matter								
	(*i*) Clay + silt, percent	7.2	7.0	14.7	4.3	6.9	8.5	12.2	
	(*ii*) Clay, percent	2.0	1.6	6.3	0.5	0.6	1.0	3.0	Not more than 1
	(*iii*) Material passing 75-micron, percent	4.1	5.0	5.1	2.3	4.0	4.1	6.6	Not more than 3
6.	Organic impurities	A	A	A	A	A	A	A	A
7.	Soundness, percent loss	23.6	26.2	36.4	17.4	24.6	8.3	24.5	Not more than 12
8.	Alkali-aggregate reactivity								
	Rc, millimoles/l	472.5	415.5	564.0	277.0	302.4	267.0	594.0	Not more than 75
	Sc, millmoles/l	52.3	48.0	115.0	40.3	49.6	38.2	165.0	Not more than 75

Note: A = absent.

In order to evaluate the suitability of laterite as fine and coarse aggregates in mortar and concrete, a detailed investigation was carried out at the Central Building Research Institute. The suitability of laterite boulders and aggregates from Goa region, for making masonry blocks was already established[10]. In the present study an attempt has been made to correlate different physico-chemical properties of laterite aggregates with their engineering properties.

Experimental programme

Samples of laterite waste were collected from various places, namely, Goa, Cannanore, Calicut, Trichur, Alwaye, Kottayam and Trivandrum, for the present study.

Laterite waste samples collected were sieved, after air drying through a 4.75-mm sieve, to separate them into fine and coarse aggregates. The samples were dried in oven at 105° to 110°C for evaluating them as

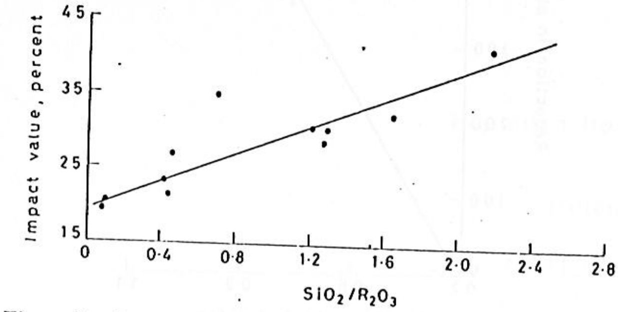

Fig 3 Relationship between SiO_2/R_2O_3 and impact value

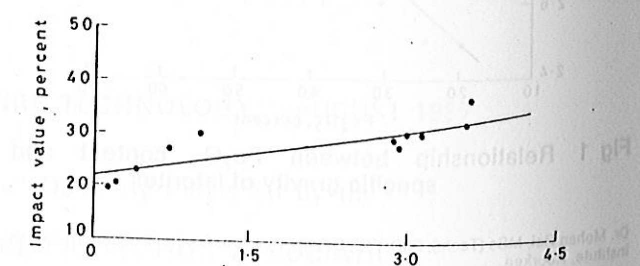

Fig 4 Relationship between SiO_2/Al_2O_3 and impact value of laterite coarse aggregates

per Indian standard methods of test for aggregate for concrete, IS: 2386 (Parts I to VIII)-1963.

Various physico-chemical properties, namely, bulk density, water absorption, apparent and true specific gravity, particle-size analysis, fineness modulus; presence of deleterious materials, soundness, alkali-aggregate reactivity and chemical composition were determined as given in relevant Indian standards.

Mechanical properties like crushing value and impact value were determined as per IS: 2386 (Part II)-1963. Mortar making properties of laterite fine aggregate samples were studied by the method given in IS: 2386 (Part VI)-1963.

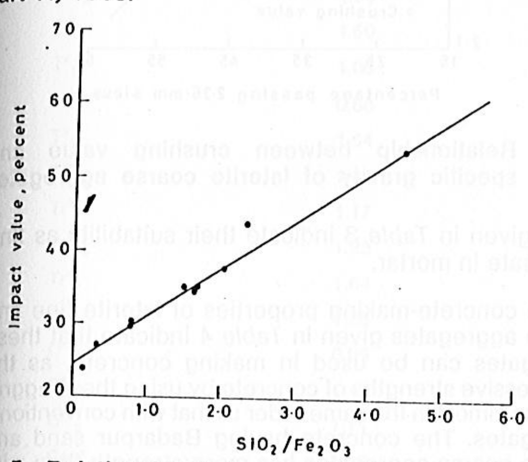

Fig 5 Relationship between SiO_2/Fe_2O_3 and impact value of laterite coarse aggregates

To study the suitability of laterite fine and coarse aggregates in making concrete, cubes having 1:2:4 mix composition by volume were cast. The concrete cubes with Badarpur sand and laterite coarse aggregates were also made for comparison. The compressive strengths of these cubes were determined at the age of 7, 28 and 90 days of water curing.

The durability of concrete cubes made as above was studied by subjecting them to alternate wetting (5 hours) and drying (16 hours) at 105°C. These cubes were subjected to 50 such cycles after 28 days of curing. The compressive strengths of these cubes were then determined.

Results and discussion

Various physico-chemical properties determined as per Indian standard test methods, given in *Tables* 1(*a*) and

TABLE 2 Mechanical properties of laterite coarse aggregates

Samples	*Crushing value at 40-t load percent fines*	*Crushing value for 10 percent fines tons*	*Impact value percent fines*
G_1	20.3	6.8	19.4
G_2	20.9	5.2	20.3
G_3	24.0	4.6	24.8
Can_1	28.2	4.7	23.1
Can_2	26.9	5.0	21.4
C_1	29.1	3.8	28.4
C_2	32.0	3.8	30.6
K	54.5	2.0	51.6
T_1	30.1	2.7	32.7
T_2	31.2	2.2	34.3
T_3	51.1	0.92	55.4
Tr_1	40.2	4.0	34.8
Tr_2	58.6	1.3	57.4
Tr_3	34.8	8.3	26.8
A	47.5	2.81	41.2

1(*b*), indicate that the fineness modulus of these fine aggregate samples varies between 2.15 to 3.28 and most of the samples fall under grading zone II. The specific gravity values of these samples vary from 2.28 to 3.18 and it has been found that the higher values of specific gravity are generally associated with samples rich in iron oxide and titaniferrous minerals[11], *Fig* 1. The water absorption of these samples varies from 3.3 to 13.3 percent which is on a very high side as compared to the specified limit[12]. The deleterious materials, as per IS: 383-1970, present in these samples were found to be in the range of 2.8 to 11.4 percent, which in some cases is on the higher side mainly due to higher percentage of clay size particles[12]. These may entail a high water requirement for making a workable mix. The quantity of organic matter in all these samples was found to be harmless. The soundness of laterite aggregates in terms of loss in percentage was greater as compared to the maximum limit of 12 percent. However, these higher values do not adversely affect the durability of concrete as has been observed when concrete cubes made from these aggregates were

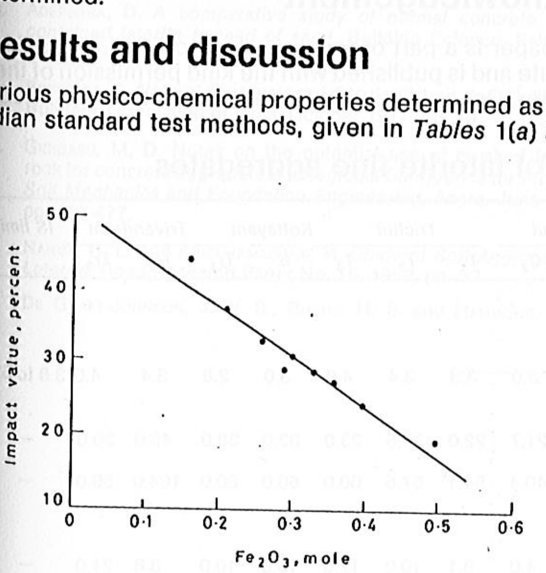

Fig 6 Relationship between Fe_2O_3 and impact value of laterite coarse aggregates

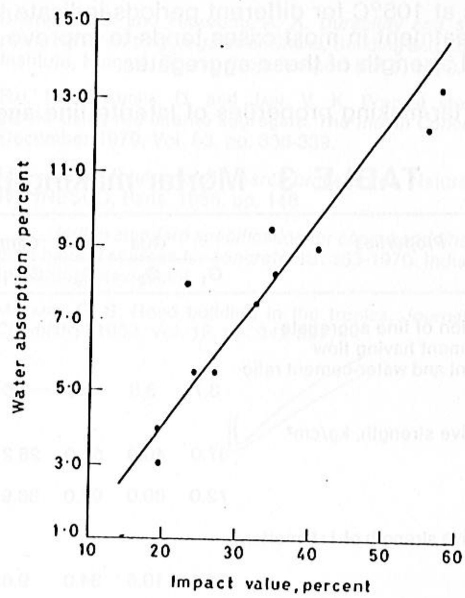

Fig 7 Relationship between impact value and water absorption of laterite coarse aggregates

subjected to alternate wetting and drying cycles, *Table* 4.

The alkali-aggregate reactivity values of these aggregates in terms of reduction in alkalinity, *Rc*, was found to be enormously high, ranging from 42.72 to 594.0 millimoles/litre, as compared to the maximum limit of 75 millimoles/litre. The plot drawn between reduction in alkalinity and silica plus alumina content of these aggregates, *Fig* 2, indicates that these values are directly proportional to each other, i.e., in the case of laterite the reduction in alkalinity as determined by chemical method is not only due to the dissolution of silica in alkali but is also due to the dissolution of alumina. The dissolution of alumina in alkali of cement will not cause any excessive expansion in mortar or concrete as the expansive gel of sodium silicate formed is not so much as to cause disruptive expansion in concrete or mortar. With the alumina of aggregate, the alkali does not form any swelling type gel; instead, water-soluble sodium aluminate is formed, which does not cause any expansion. Hence, on the basis of chemical test, laterite having a higher value of reduction in alkalinity may be considered harmless.

The mechanical properties of laterite coarse aggregate samples determined in terms of crushing and impact values, *Table* 2, indicate that in most cases, the impact values vary in the range of 19.4 to 41.2 percent as compared to 45 percent maximum specified limit. The plots, *Figs* 3 to 6, drawn between impact value and SiO_2/R_2O_3, SiO_2/Fe_2O_3 or Fe_2O_3 indicate the direct relationship between impact value and Fe_2O_3 content of these aggregates; as the Fe_2O_3 content increases, the impact value decreases. This correlation has been reported by Millard[13] and De Graft-Johnson and co-authors also[7]. No correlation has been reported between impact value and SiO_2/R_2O_3 or SiO_2/Ai_2O_3 ratio of these aggregates. Studies by De Graft-Johnson[7] have shown that specific gravity and water absorption are among the index properties which significantly correlate with the strength of laterite rocks. The plot between impact value and water absorption, *Fig* 7, indicates the correlation between them. The relationship between specific gravity and crushing value of these aggregates, *Fig* 8, also confirms the trend obtained by other workers[7]. It has also been noticed that in general from Goa to Trivandrum these values increase, i.e., the aggregates become softer from Goa to Trivandrum. The effect of heat treatment on aggregates at 105°C for different periods indicate that the heat treatment in most cases tends to improve the mechanical strength of these aggregates.

The mortar-making properties of laterite fine aggregates given in *Table* 3 indicate their suitability as fine aggregate in mortar.

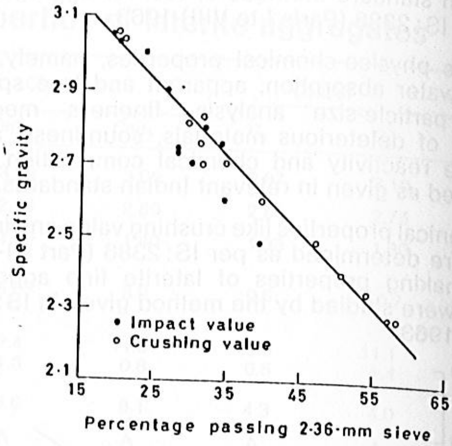

Fig 8 Relationship between crushing value and specific gravity of laterite coarse aggregates

The concrete-making properties of laterite fine and coarse aggregates given in *Table* 4 indicate that these aggregates can be used in making concrete, as the compressive strengths of concrete by using these aggregate are almost in the same order as that with conventional aggregates. The concrete having Badarpur sand and laterite coarse aggregates has more strength than with the laterite fine aggregate, because due to higher water absorption characteristics the water requirement enormously increases for the same workability with laterite fines. The lower compressive strength values of concrete in some cases are due to slack softness of coarse aggregate and, consequently, due to their higher water requirement.

Concrete cubes having laterite fines or Badarpur sand with laterite coarse aggregates, after subjecting them to 50 cycles of alternate wetting and drying, indicate that the concrete is durable as the compressive strengths of these cubes are higher than the 28-day strength.

Acknowledgement

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TABLE 3 Mortar-making properties of laterite fine aggregates

Sr. No.	Properties	Goa			Cannanore		Calicut		Trichur			Kottayam	Trivandrum			IS limit
		G_1	G_2	G_3	Can_1	Can_2	C_1	C_2	T_1	T_2	T_3	K	Tr_1	Tr_2	Tr_3	
1.	Consumption of fine aggregate for 2kg cement having flow 110 percent and water-cement ratio of 0.6, kg	3.7	3.6	5.0	3.6	3.3	3.6	3.0	3.3	3.4	4.0	3.0	2.8	3.4	4.0	3.8 to 52
2.	Compressive strength, kg/cm²															
	7 days	37.0	40.0	51.0	28.2	21.7	23.8	21.7	22.0	22.5	23.0	32.0	38.0	46.0	30.0	–
	28 days	72.0	80.0	92.0	66.9	68.0	48.6	40.4	54.1	57.6	60.0	66.0	80.0	104.0	56.0	–
3.	Compressive strength of 1:6 mortar, kg/cm²															
	7 days	10.1	10.5	34.0	9.6	5.4	6.1	4.0	9.1	10.0	12.0	10.0	10.0	8.8	21.0	–
	28 days	28.0	27.4	59.0	18.5	10.9	10.6	9.0	19.2	21.0	23.0	24.0	19.0	18.6	40.0	–
	90 days	35.0	34.7	–	27.1	19.6	18.0	16.1	30.6	40.0	41.2	43.0	28.0	30.2	61.6	–

TABLE 4 Concrete-making properties of laterite coarse aggregate using laterite fines or Badarpur sand as fine aggregate, mix 1:2:4 by volume

Sr. No.	Sample	Water-cement ratio	Compressive strength kg/cm²			Compressive strength after durability test kg/cm²
			7 days	28 days	90 days	
1.	G^x_1	1.63	41	71	84	90
2.	G^{xx}_1	1.07	79	118	133	142
3.	G^x_2	1.50	40	70	99	91
4.	G^{xx}_2	1.00	87	125	148	157
5.	G^x_3	1.50	81	117	136	148
6.	T^x_1	1.06	58	76	88	123
7.	T^{xx}_1	0.88	68	107	121	140
8.	T^x_2	1.54	34	55	61	78
9.	T^{xx}_2	1.41	43	65	76	89
10.	Tr^x_1	1.17	50	106	124	159
11.	Tr^{xx}_1	1.23	42	91	120	127
12.	Tr^x_2	1.64	25	65	88	91
13.	C^x_1	1.25	33	61	74	84
14.	C^{xx}_1	0.95	46	90	102	110
15.	C^x_2	1.44	20	45	53	56
16.	C^{xx}_2	1.11	37	69	87	100
17.	Can^x_1	1.18	45	82	96	104
18.	Can^{xx}_1	0.89	64	91	106	116
19.	$Control^x$	0.99	45	65	81	90
20.	$Control^{xx}$	0.60	75	120	130	141

Notes: 1. *x* Using laterite fine and coarse aggregates.

2. *xx* Using Badarpur sand and laterite coarse aggregates.

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