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Calcretic and ferricretic duricrusts of the Thar Desert, India: their geotechnical appraisal as a road paving aggregate

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Abstract

This paper presents the results of laboratory tests conducted to evaluate the suitability of calcrete and ferricrete as road paving aggregates. Most of these residual aggregates are gravel dominated (A-1 class) with low percentage of non-plastic fines. The maximum dry density (MDD) and optimum moisture content of these aggregates are controlled primarily by the size gradation and compaction energy. Specimens compacted using higher energy result in increase of MDD than those specimens compacted under low energy. Similarly, the California bearing ratio (CBR) also increases manifold (as much as 97.08%) when compacted under higher compaction energy. Aggregate impact values, a measure of toughness of these aggregates vary from 12.8 to 47.5%. Both calcrete and ferricrete exhibit special properties such as self-stabilization and increase in CBR after soaking. Obtained laboratory results on size gradation, CBR and aggregate impact values fulfils the Indian Road Congress (1978) specifications for the base and sub-base courses of water bound macadam (WBM) roads. © 1999 Elsevier Science B.V. All rights reserved.

Keywords: Calcrete; Ferricrete; Pavement; Thar Desert

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1. Introduction

Residual soil and weathered aggregates have widely been used in tropical region for low cost road construction. Among different kinds of residual soils, ferricrete (laterite) gained much significance (Gidigasu, 1980; Alao, 1983; Gidigasu et al., 1987) due to its wide distribution in tropical countries. However, significance of another residual soil namely calcrete has been utilized recently for low cost road pavements in arid and semi arid terrain (Horta, 1980; Al-Sulami et al., 1991; Ramakrishnan and Tiwari, 1998). Similar to any other desertic terrain, road construction in Thar Desert is also jeopardized due to the scarcity of locally available, traditional road paving aggregates. Hence, it becomes imperative to carry out geotechnical studies of these widely prevalent aggregates for their selection as an alternate, local road paving aggregate.

2. Environment and geology

Climatically semiarid–arid–hyper arid environments characterize the Thar Desert on E–W transects. The rainfall, aridity index, diurnal variations in temperature and wind regime adequately reflects prevalence of these three fold environmental regions of the Thar Desert.

Geologically, the area comprises of numerous

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litho-stratigraphic sequences ranging in age from Precambrian to Tertiary periods. These litho types (viz. granites, rhyolites — Precambrian; sandstones, shales, limestones — Jurassic and Cretaceous; sandstones, shales, limestones, evaporates — Tertiary) are enveloped by Recent to sub-Recent dunal material (Pareek, 1981). These dunal sand and rock masses underwent weathering, resulting in the development of variety of duricrusts. The most widely prevalent among these duricrusts are calcrete and ferricrete. Developmental stages in calcrete include powdery calcrete, nodular calcrete, honeycomb calcrete and hardpan types in progression. They are associated with dunes, interdunes, alluviums and pediments. Present study however cover only the hard nodular calcretes associated with dunal and inter dunal areas, on account of their wide distribution and near surface occurrence. Ferricrete on the other hand occurs as massive, sheeted and pisolithic forms.

3. Methodology and approach

The methodology adopted here includes collection of both disturbed and undisturbed samples from thirty locations, covering semiarid–arid–hyper arid environmental domains (Fig. 1) following the methods of the Earth Manual (1965). Depth of sample collection vary from 0.1 to 3.5 m. The geotechnical attributes such as grain size parameters, index properties, compaction (Standard and Modified Proctor), California Bearing Ratio, Aggregate Impact values are evaluated by adhering Indian Standard test procedures (IS: 2720 part 4, 5, 7, 16; IS 5640). Indian Road Congress (IRC, 1978) specifications are adhered to in evaluating the suitability of these aggregates for use in base and sub-base courses.

4. Results

4.1. Chemistry and mineralogy

Calcrete comprises of calcite (40–60%), quartz (30–45%) and feldspars (10–15%). Other minerals in minor proportions are mica, pyroxene, amphibole and clays (chlorite, montmorillonite, illite). The calcitic cement is commonly low “mg”; however, dolomites are also seldom encountered. Major oxide chemistry of calcrete is CaO (40–65%), SiO_2 (30–50%), Al_2O_3 (8–15%), MgO (2–12%) and Fe_2O_3 (1–5%).

Ferricrete is predominantly composed of Al-goethite and quartz. Occurrence of maghemite, haematite, magnetite and kaolin are also evidenced. The major oxide chemistry of ferricrete is: SiO_2 (19–72%), Fe_2O_3 (7.6–25%), Al_2O_3 (13.4–38%), CaO (0.8–22.2%), MgO (1–20.3%). In some cases, calcretization of ferricrete results in an increase in the CaO and MgO content.

4.2. Geotechnical appraisal

4.2.1. Index properties and classification

The evaluated index properties of duricrust aggregates include: natural moisture content (NMC); bulk density; liquid limit (LL); plastic limit (PL); and grain size gradation [Table 1 and Fig. 2(a and b)]. The NMC of these aggregates vary in accordance to the depth of duricrust development, type and geomorphic association. Powdery calcrete, soft nodular calcrete and calcrete associated with inter-dunal areas have higher NMC than the hard nodular, honeycomb and hardpan calcrete of dune association.

Similarly, the field density of calcrete also depends on the intensity of calcretization and nature of source sediments that are calcretized. Nodular calcrete of silty sand association with different percentage of sand matrix have field density ca 900 kg m^{-3}. While coalesced nodular calcrete, hard pan variety, calcretized gravelly sand and weathered pediments have field density between 1200 and 1300 kg m^{-3}. Ferricretes in general have higher field density ($1200–1537 \text{ kg m}^{-3}$) with a variation in NMC between 7.1 and 28.7%. The grain size parameters of calcrete and ferricrete indicate predominance of gravel size fractions with a well-graded nature. However, some of the calcretes and ferricretes are uniformly graded. Gap gradation is not commonly observed, though a near gap gradation is noticed

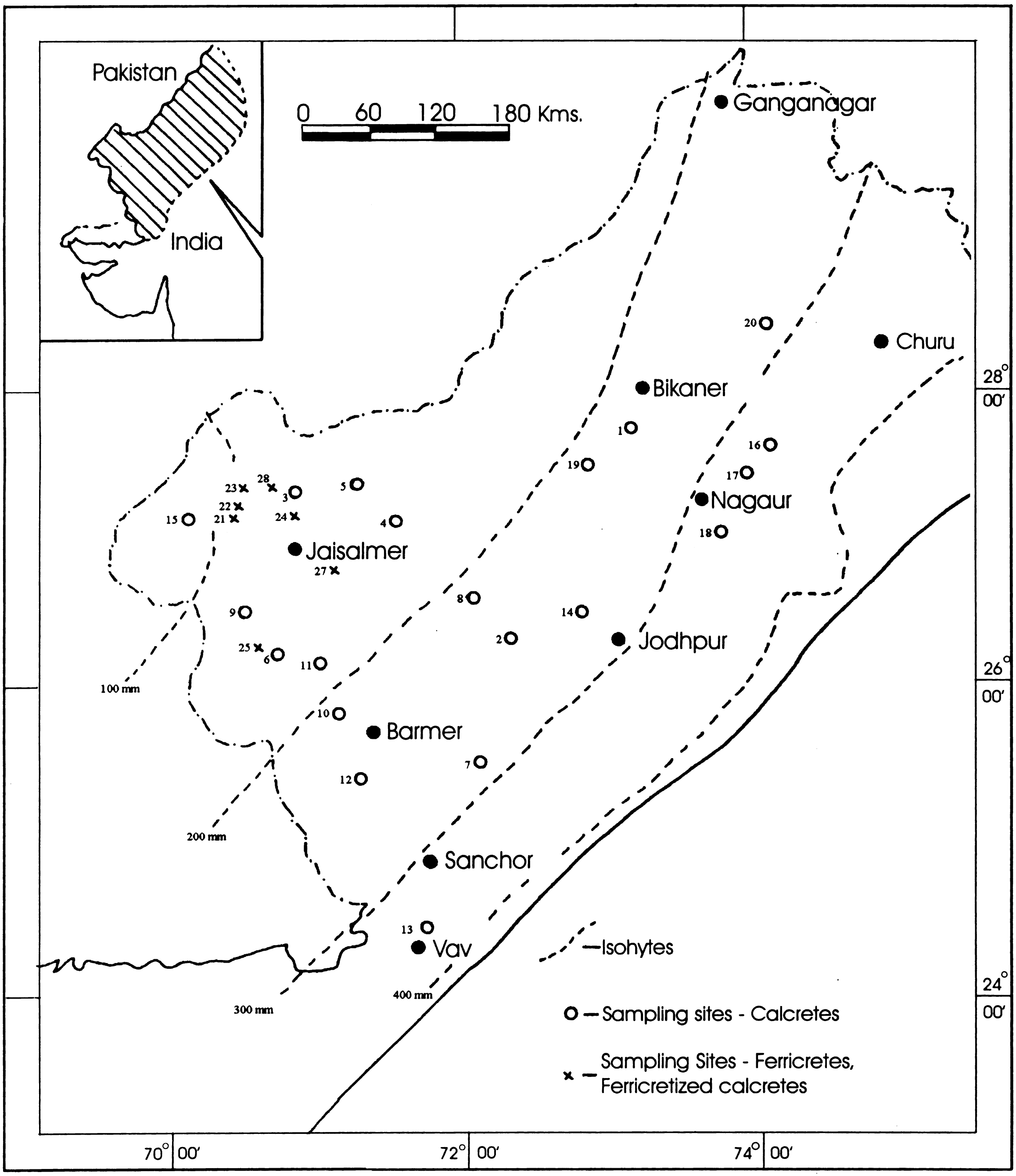


Fig. 1. Location map of the study area.

in some of the ferricretes. The percentage of fine (<0.075 μm) of calcrete vary from 0.2 to 35.8%.

Ferricrete in general have low percent of fines (2–5%). However, the dissected and calcretized ferricretic horizons have percentage of fines ranging from 2 to 23.2%. The mean grain diameter

Table 1
Index properties of calcretes and ferricretes

Sample No.	Location	% Fine	Mean grain diameter (mm)	LL and Pl (%)	NMC (%)	Field density (kg m^{-3})	Soil classification	
Calcretes								
1	Napasar	0.2	6.2	NP	7.1	1216	GP	A-1-a (0)
2	Shergarh	18.0	1.5	NP	14.8	872	SM	A-1-b (0)
3	Sultana	2.9	3.5	NP	15.7	882	GW	A-1-a (0)
4	Bhukan	14.3	1.25	NP	18.7	1357	SM	A-2-4 (0)
5	Kanod Rann	20.4	2.5	NP	19.0	972	GM	A-1-b (0)
6	Bersi	35.8	0.25	NP	5.6	1181	SM	A-2-4 (0)
8	Dechchu	11.8	4.5	NP	14.3	881	SM	A-1-b (0)
9	Khudi	16.5	1.50	NP	9.6	1434	SM	A-1-b (0)
10	Shersing dhani	14.4	0.25	NP	12.6	1450	SM	A-2-4 (0)
11	Derasar	4.6	0.15	NP	9.2	1358	SP	A-3 (0)
15	Longewala	21.1	1.9	NP	18.1	1120	SM	A-1-b (0)
16	Surpalia	4.4	0.2	NP	23.7	920	SW	A-3 (0)
18	Nimbijodhan	1.1	7.0	NP	14.1	ND	GP	A-1-a (0)
19	Raneri	19.9	3.1	NP	31.2	1458	SM	A-1-b (0)
20	Sardarsahar	33.0	0.25	NP	27.3	921	SM	A-2-4 (0)
Ferricretes								
21	Bandah	5.9	4.80	NP	24.0	1268	GW	A-1-a (0)
22	Asutar	3.9	9.0	NP	7.1	1279	GW	A-1-a (0)
23	Ramgarh I	10.4	1.2	NP	26.0	1147	GM	A-1-b (0)
24	Khenya	10.9	3.2	NP	17.4	1537	GM	A-1-b (0)
25	Girab	2.0	30.0	NP	28.7	ND	GW	A-1-a (0)
26	Ramgarh II	[a]	[a]	[a]	[a]	[a]	[a]	[a]
27	Ramgarh III	[a]	[a]	[a]	[a]	[a]	[a]	[a]
28	Savanta	[a]	[a]		[a]	[a]	[a]	[a]
29	RD 105	[a]	[a]	[a]	[a]	[a]	[a]	[a]

Sample Nos 7, 12–14 and 17, calcretes poorly developed.
[a] Aggregates are massive.
ND, Not determined.

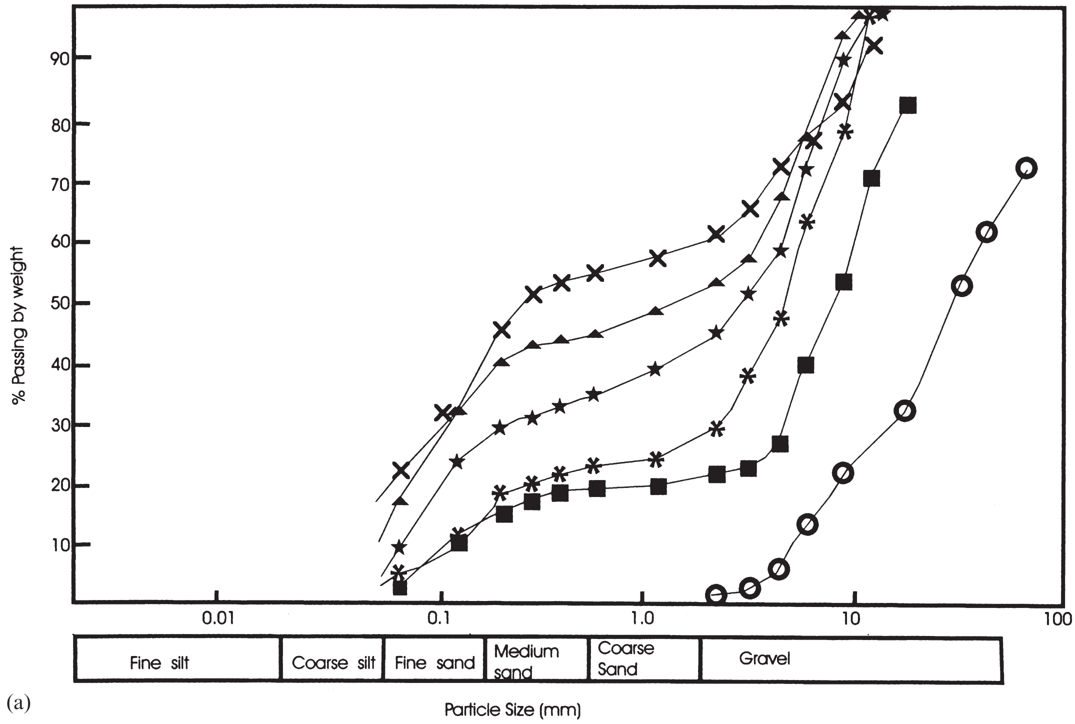
(D_{50}) of calcretes vary from 0.25 to 6.2 mm and that of ferricretes are 0.28 to 30 mm. Angularity of the aggregates as expressed by the Roundness Index (Powers, 1953) indicate that nodular calcrete is angular to sub-angular and ferricrete is sub-angular to sub-rounded. The Atterberg limits evaluated on the fines indicate that both calcretes and ferricretes are non-plastic.

In the Unified Soil Classification, calcrete aggregates can be grouped under gravel (GW, GP); sand (SW, SM) classes. Ferricrete generally fall under gravel class (GW and GM). In the A.A.S.H.T.O. (1978) aggregate classification, gravel size domination of these aggregates is reflected by a wide prevalence of A-1-a and A-1-b classes. The non-plastic, sand dominated samples fall under A-2-4 (0) class and gravel–sand mixture samples are of the A-3 class.

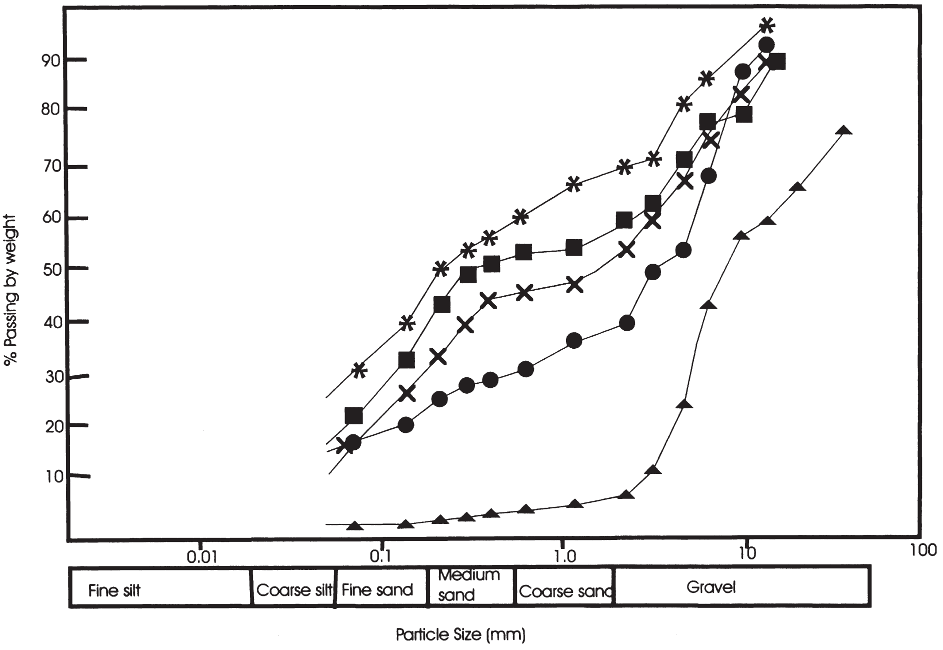
4.2.2. *Compaction characteristics*

As compaction characteristics are controlled to a great extent by index properties (Mohan and Paul, 1975; Gidigasu, 1983; Gidigasu et al., 1987; Saha and Chattopadhyay, 1988), compaction characteristics of calcrete and ferricrete are evaluated for representative A.A.S.H.T.O. and USC classes (Table 2). Maximum dry density (MDD) and optimum moisture content (OMC) are estimated using both standard and modified Proctor compaction energies.

Calcretes compacted using standard Proctor energy depict a range of MDD (1753 and



(a)



(b)

Fig. 2. (a) Size gradation curves for calcretes. (b) Size gradation curves for ferricretes.

Table 2
Compaction characteristics of calcreters and ferricretes

Sample No.	OMC (%)	MDD (kg m^{-3})
3	14	1764
5	12.8	1782
6	13.6	1753
9	11.2	1921
10	11.1	1911
	10.2[a]	2200[a]
11	13.1	1902
	11.8[a]	2277[a]
21	10.5	2130
	11.1[a]	2592[a]
22	8.4	2254
23	11.1	2263
24	9.4	2231
	10.9[a]	2540[a]
A	8.7	2080
B	10.0	2049
C	10.7	1965

[a] Values estimated under modified Proctor compaction.

1921 kg m^{-3}) with a corresponding variation in OMC (11.1–13.6%). The plotted compaction curves [Fig. 3(a–c)] further elucidate that:

(1) Two distinct groups of compaction behaviour prevails within calcrete as indicated by changes in MDD values (ca 1750 kg m^{-3} for the first and 1900 kg m^{-3} for the latter) within almost the same range of OMC.
(2) With the increase in moisture content, rise and fall of MDD is gradual.

Within a narrow spectrum of OMC, calcretes show a significant variation in MDD. It is apparent from the index properties that well graded aggregates yield more MDD than uniformly and gap graded aggregates.

Ferricretes and calcretized ferricretes exhibit a slightly higher MDD range (2130–2263 kg m^{-3}) at a relatively low OMC (8.1–11.1%) than calcretes. High MDD values of ferricretes can be mainly attributed to their mineralogy and well-graded nature. In both ferricretes and calcretized ferricretes, MDD rise and fall is rapid with the increase in moisture content. The compaction curves of calcretized ferricretes [Fig. 3(c)] indicate that the introduction of lime to ferricretes results in a lowering of MDD (1965–2088 kg m^{-3}), without a significant change in OMC (8.7–10.2%).

Compaction under modified Proctor energy resulted in the increase of MDD for both calcretic (2178–2200 kg m^{-3}) and ferricretic (2540–2592 kg m^{-3}) aggregates.

4.2.3. *California bearing ratio (CBR)*

Akin to the compaction characteristics, the strength of aggregates are also controlled by the index properties (Gidigasu et al., 1987). Hence, the CBR of representative aggregate classes are evaluated at OMC and MDD achieved under standard and modified Proctor compaction energies (Table 3). Similarly to evaluate the impact of water logging, on compaction and strength, CBR is evaluated both under soaked and unsoaked conditions.

The CBR of unsoaked calcrete samples range between 8.6 and 27.3%, while their corresponding soaked counter parts are in the range of 15.2–35.7%. Ferricretic aggregates have comparatively higher CBR than calcretes (unsoaked: 14.6 and 24.8%; soaked: 38.5 and 36.2%). It is shown that the soaking of these aggregates did not result in swelling. But, moisture content of both calcretes and ferricretes after soaking increases arbitrarily (0.25–0.80%). The CBR values of calcretized ferricretes fall in between that of calcrete and ferricrete (unsoaked CBR 14.6 and 31.0%; soaked CBR 37.2 and 42.9%).

It is interesting to note that calcrete that yields a low CBR value (14.2%) when compacted using standard Proctor energy yields high CBR values (48.2%) at modified Proctor compaction. After soaking, the CBR further increases to 79.56%. Similarly, ferricrete also exhibits an increase in CBR (as much as 97.1%) under modified Proctor compaction.

4.2.4. *Aggregate impact values (AIV)*

AIV, an expression of toughness of the aggregates also forms a vital IRC (1978) specification in selecting aggregates for different courses of the pavement. The AIV of calcretes has a wide range from 47.5 to 12.8%. However, the

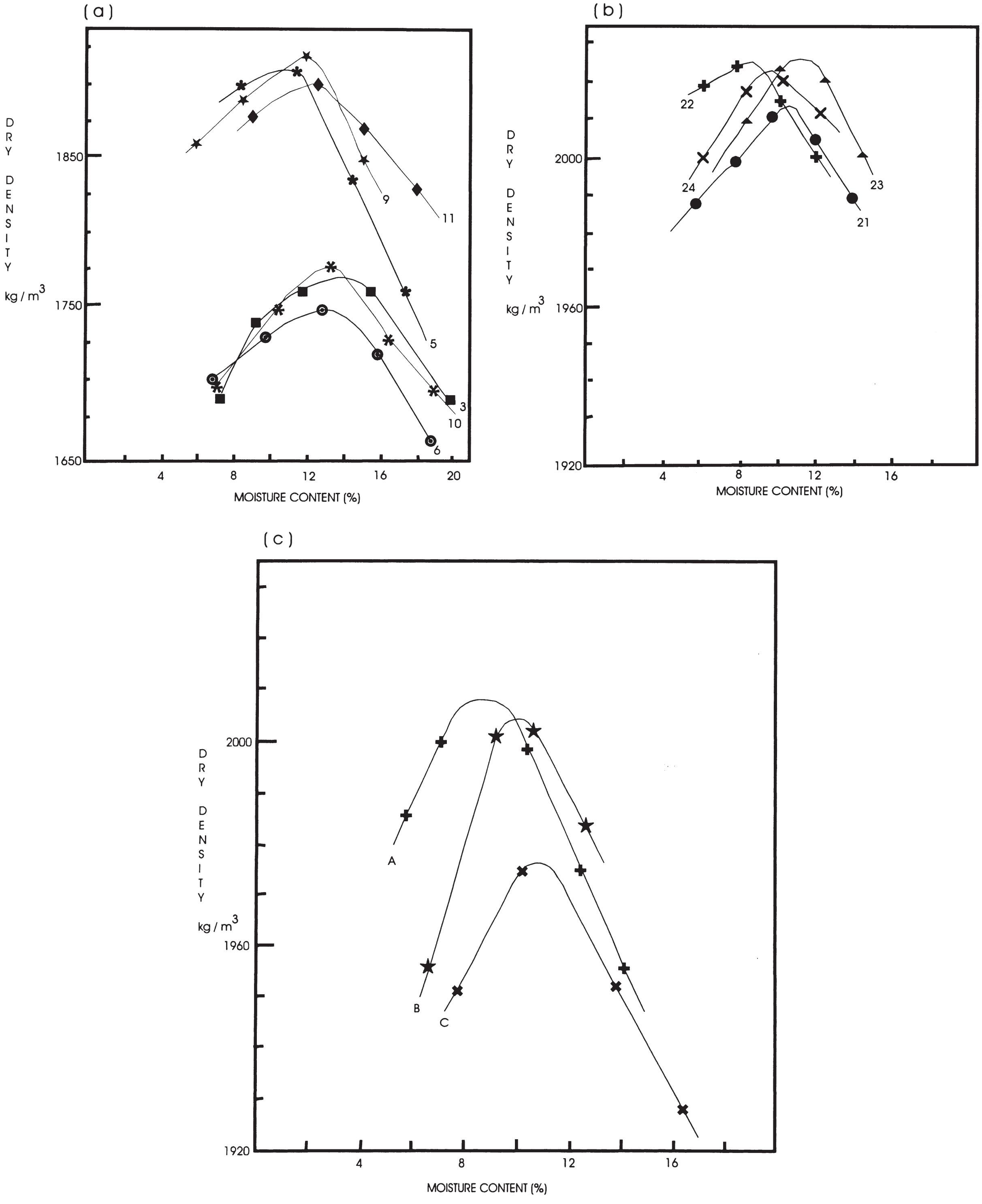


Fig. 3. Compaction curves: (a) calcretes; (b) ferricretes; and (c) calcretized ferricretes.

Table 3
Strength parameters of calcretes and ferricretes

Sample No.	California bearing ratio (%)		Aggregate impact value (%)
	Un-soaked	48 h soaked	
3	—	—	26.8
5	—	—	47.5
6	8.6	15.2	19.6
9	10.5	34.1	12.8
10	27.3	35.7	23.2
11	14.2	34.1	31.5
	48.2[a]	79.6[a]	
21	—	—	30.8
22	24.8	38.5	13.9
23	—	—	29.3
24	14.6	36.2	23.8
	97.08[a]	119.7[a]	
B	31.0	37.2	—
C	14.6	42.9	—

[a] Values estimated under modified Proctor compaction.

AIV of ferricretes are in the range of 25–30% (Table 3).

5. Discussion and conclusions

It is evident from the results detailed above that calcretic and ferricretic aggregates are dominantly coarse, gravelly aggregates with less percentage of non-plastic fines (A-1 a and b class). These aggregates differ from other tropical residual aggregates (Gidigasu et al., 1987; Saha and Chattopadhyay, 1988) in that, the fines do not control the compaction and strength by virtue of its non-plastic nature. But size gradation seems to play a key role in compaction control. Generally, well graded aggregates enable better compaction (MDD: 1902–1921 kg m^{-3}) than that of poorly graded or uniform graded aggregates (MDD: 1753–1764 kg m^{-3}). It is apparent form the MDD and OMC values of calcrete and ferricrete aggregates (compacted under both standard and modified Proctor energies) that better compaction can also be achieved under higher compaction energies. Calcretes that are used for road construction in Algeria, Australia and Kuwait are expansive and yield relatively low MDD and high OMC (Horta, 1980; Akpokodje, 1985; Al-Sulami et al., 1991). In contrast to this, calcretes of the study area are non-expansive and give better compaction control.

Though CBR of these aggregates are low at unsoaked conditions (8.6–31%), it is interesting to note that, both calcretes and ferricretes show manifold increase in the CBR after soaking (15.2–42.9%). This increase in strength after soaking can be attributed to development of apparent cohesion. Even specimens having very low percentage of fines exhibit increase in CBR after soaking. This phenomenon can be mainly attributed to non-plastic, silty nature of the solum that were calcretized or ferricretized, rather than to abundance of fines alone.

Akin to the observations of Al-Sulami et al. (1991), calcrete and ferricrete of the study area also exhibit an increase in CBR, when compacted under higher energies. Thus calcretes yielding low CBR values (14.2%) under standard Proctor compaction yield high CBR values (48.2%) when compacted under modified Proctor energy. In the case of ferricrete, this increase is as much as 97.08%.

Furthermore, the authors (Ramakrishnan and Tiwari, 1998) have also found self-stabilization phenomenon (a property to indurate when compacted and allowed to dry) in these aggregates. This property is of vital significance in improving the strength of these aggregates in rainfall deficit,

Table 4
Grading specifications for granular sub-base course materials (IRC, 1978)

Sieve designation	Percentage by weight passing		
	Grading I	Grading II	Grading III
80 mm	100	100	100
63 mm	90–100	90–100	90–100
4.75 mm	35–70	40–90	50–100
75 μm	0–20	0–25	0–30
CBR (minimum)	30%	25%	20%

Note: the Liquid Limit and Plasticity Index of the fractions passing 425 μm should be <25 and 6%, respectively.

arid tracts of the study area. Self-stabilization observed in calcretes and ferricretes is attributed to:

(1) re-crystallization of calcite (in calcretes) or sesquioxides (in ferricretes); and
(2) neoformation of calcium silicate hydrates, calcium aluminate hydrates due to the reaction of lime and alumino silicates such as chlorite, illite etc. (Akoto and Singh, 1981).

Horta (1980) observed a maximum induration after 4 days of compaction for calcretes in the field. However, in the absence of any field trials, similar observations are yet to be established in the investigated area.

The evaluated geotechnical characteristics of calcretes and ferricretes fulfil the IRC (1978) specifications on size gradation (Table 4) and aggregate impact values (maximum 40%) for water bound macadam roads. From the above cited results, it is apparent that required specifications on CBR (minimum 30%) can also be achieved under higher compaction energies. Considering various properties of these aggregates such as well graded and non-plastic nature, enhancement of CBR at higher energies of compaction, increase in CBR values after soaking and self-stabilization; the authors suggest that they can be utilized in sub-base, base courses construction of WBM roads with a proper compaction control.

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