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CONTENTS

"A STUDY OF ROAD AGGREGATES FOR USE IN BLACK TOP SURFACINGS"

By

K. P. Nair *

&

B. S. Gogte *

CONTENTS

SYNOPSIS

Based on the results of tests carried out on different types of aggregates obtained from all over India, this study stresses the importance of testing the adhesion characteristics of the road aggregates, in addition to their physical properties, for use in black top surfacing. It is found that even aggregates of the same geological group have widely varying adhesion properties. The petrographic analysis is carried out to see as to how far the surface texture, grain size and mineralogical composition of the road aggregate are responsible for the adhesion between it and the binder. Suitable binders are also recommended for aggregates with very low stripping resistance. The findings of this study will help to a great extent in the proper choice of an aggregate and binder for use in black top surfacings.

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* Central Road Research Institute, New Delhi.

1. INTRODUCTION

1.1. The progress of a country is usually linked with the length of all-weather roads it has. On area basis, India has at present only about 28 miles of roads per hundred square miles. This is likely to be increased to over 50 miles in 1980-81.

1.2. Of the various types of the road surfacing, the black top paving comprising of the surface dressing and the premix open texture carpet has the greatest length. For the construction of the dense graded bituminous and concrete roads, though far superior, costly machinery as well as efficient quality control and knowledge of modern laying techniques are essential. Uptill 1951, there were only 1,075 and 12,845 miles of concrete and black top surfaced roads respectively in India, while, in 1956, the figures rose to 2,400 and 30,940 miles respectively[2] which clearly shows the rapid and considerable increase in the length of black top surfacing.

1.3. Availability of suitable road stones (which form over 90 per cent of the surfacing) is the foremost requisite in a road project. It has to withstand the detrimental effects of traffic and weather and thus affect the life of the road. In a vast country like ours, numerous varieties of stones are used for surfacing of the roads. Some of these especially of the granite sand quartzite groups, are quite satisfactory as far as their physical standards are concerned, but have comparatively lower stripping resistance compared to the trap or charnockite varieties. However, due to their existence in abundance, they have to be made good use of for construction of roads from economy point of view, after choosing the best binder to withstand stripping.

1.4. To avoid failure of the surfacing due to physical drawbacks or stripping, the aggregate to be used in road making, should be tested in advance. With this object in view, samples of road aggregates were obtained from all over India and were tested for their suitability based on their physical properties and resistance to stripping when coated with bitumen and tar. Suitable binders are also recommended for those aggregates with very low stripping resistance.

1.5. While the physical studies deal with the properties such as crushing, abrasion, absorption, adhesion with bituminous binders, etc., detailed petrological study was also made dealing with surface texture, grain size and mineralogical composition of the stones from which suitability of an aggregate for use in black top pavements can be predicted to a certain extent.

2. THE ROAD AGGREGATES RECEIVED

2.1. 108 samples of road aggregates being used for black top pavements were received for this study from various Highway departments of the country. Data regarding the name of the quarry and the source or area where available were also collected.

Details based on experience about the suitability of the aggregates for bituminous road construction are available only for a few samples all of which invariably show satisfactory behaviour.

2.2. Maximum number of samples were received from Bombay (Maharashtra and Gujarat) (34), followed by Andhra Pradesh (26), Madras (14), Madhya Pradesh (9), Bihar (7), Mysore (6), Punjab (4), Rajasthan (2), Assam (1), West Bengal (1), Himachal Pradesh (3) and Delhi (1). No samples were received from Uttar Pradesh, Kerala, Orissa and Kashmir. Where more than one sample was sent from a place, though geologically belonging to the same group, they were tested separately, especially when the quarries from where obtained were different. In the case of mixture of two or more varieties, based on the type of rock, *colour or surface* texture, e.g., the samples from Durg (M.P.) contained both limestone and sandstone; the samples from Dadri (Punjab) contained 7 types of quartzites and 2 of dolerites; the grey and pink granites from Karim Nagar (A.P.) and three varieties of granites from Bhiwani (the granite gneiss a medium to coarse pink variety as well as a medium textured and weathered grey type) were separated and tested. The granite samples from Darjeeling were also separated into three groups for stripping tests. In this connection it is of interest to note that "Shergold" is also of the view that results obtained on a sample from one part of a quarry sometimes differ from those obtained on a sample taken at the same time from another part of the same quarry and considers only the tests made recently as valid[3].

2.3. Samples of aggregates received from 12 sources were too small in quantity for testing purposes. Three samples could not be separated into their constituents. Thus, while physical tests could not be carried out on samples from 15 sources, stripping test could not be done on samples from 13 sources only (Tables 1 and 2). On the whole, 122 samples were tested for evaluating their adhesion characteristics with bitumen and tar, while 114 samples were tested for specific gravity, absorption, crushing value and abrasive resistance. 111 samples were put to a megascopical examination, while 100 samples were cut in thin sections and analysed microscopically. 30 samples representing various types of road stones were examined in detail for the quantitative study of the mineralogical composition.

TABLE 1

Results of Physical Tests

Type of Aggregate

S. No.	Specific gravity Bulk S.S.D.	Absorption Per cent	Crushing value (I.S.)	Wear Per cent	Remarks
			'A' Trap		
1.	2.89	1.4	24.0	12.9	
2a.	2.99	0.6	16.7	8.9	
2b.	2.90	0.8	14.3	8.9	
3.	2.82	1.0	18.8	9.4	
4.	2.97	1.0	16.2	7.9	
5.	2.89	1.2	17.2	9.5	
6.	2.94	2.3	17.1	10.7	
7.	2.71	5.2	22.0	16.0	Vesicular
8.	2.94	1.6	16.8	11.0	
9.	3.05	0.4	15.9	8.0	
10.	2.97	1.2	16.3	10.4	
11.	2.94	1.3	16.7	10.0	
12.	2.89	0.9	14.8	8.5	
13.	2.90	0.7	15.0	8.8	
14.	2.88	1.1	17.4	8.6	
15.	3.00	1.1	16.4	10.2	
16.	2.94	1.1	12.1	8.2	
16a.	2.95	1.1	17.2	10.7	
17.	2.90	0.3	11.2	8.1	
18.	3.01	0.4	13.3	8.7	
19.	2.81	3.3	21.6	13.4	Vesicular
20.	2.87	1.0	17.4	9.0	
21.	2.92	1.0	15.6	11.7	
22.	2.96	1.0	16.0	9.2	
23a.	2.99	1.5	16.3	9.5	
23b.	2.95	1.0	15.1	8.6	
24a.	2.90	0.8	17.3	10.3	
24b.	2.88	1.0	18.1	10.3	
25.	2.89	1.6	18.2	10.4	

TABLE 1 (*contd.*)

S. No.	Specific gravity Bulk S.S.D.	Absorption Per cent	Crushing value (I.S.)	Wear Per cent	Remarks
26.	2.83	1.6	17.8	11.4	
27.	2.85	1.7	16.0	10.2	
28.	2.95	1.4	15.1	9.1	
29.	2.95	1.1	16.1	9.5	
30.	2.86	1.4	16.2	10.0	
31.	2.95	0.9	15.5	8.4	
32.	2.80	1.4	27.8	23.9	
33.	3.01	0.9	16.4	7.5	
34.	2.98	0.7	26.3	19.5	
35a.	3.28	0.3	18.4	16.7	
35b.	3.36	0.3	22.0	21.9	
			'B' Granite		
36.	2.67	1.1	16.9	12.8	
37.	2.69	0.3	22.0	13.4	
38a.	2.67	0.3	22.9	15.4	
38b.	2.62	0.3	27.2	21.2	
39a.	2.72	0.2	29.5	25.9	Quartz fissured
39b.	2.64	0.3	25.0	17.9	
40.	2.75	0.4	20.5	17.6	
41.	2.65	0.3	26.1	14.4	
42.	2.67	0.5	32.5	27.2	Alteration of potash feldspar and mica
42a.	2.63	0.4	27.3	20.0	
43.	2.71	0.4	21.1	14.0	
44a.	2.63	0.4	29.8	26.0	Microclinic, alteration of feldspar
44b.	2.70	0.2	23.0	20.0	
45.	2.68	0.3	22.7	15.5	
46.	2.63	0.7	31.6	35.4	Quartz fissured, alteration of bulk minerals
47a.	2.66	0.8	27.1	19.7	Gneiss
47b.	2.73	1.3	20.9	15.1	Pink colour

TABLE 1 (*contd.*)

S. No.	Specific gravity Bulk S.S.D.	Absorption Per cent	Crushing value (I.S.)	Wear Per cent	Remarks
47c.	NO		TEST		Grey colour
48.	2.65	0.5	29.6	31.8	Micaceous, alteration in bulk minerals
49a. } 49b. }	2.64	0.5	27.0	29.1	
50.	2.64	0.4	20.8	14.5	
51.	2.61	0.7	31.3	30.7	Weathered, grey and light brown
52.	2.69	0.3	27.8	21.4	
53.	2.74	0.5	24.5	19.5	
54.	2.64	0.3	27.9	19.6	
55.	2.66	0.3	22.2	15.4	
56.	2.65	0.4	29.6	23.9	Decomposition factor high, highly potassic
57.	2.64	0.2	26.0	19.6	
58a. } 58b. } 58c. }	NO		TEST		Weathered Micaceous Pegmatite
59.	2.73	0.5	19.8	14.3	Schists
60.	2.75	0.4	18.1	12.8	Do.
61.	2.76	0.3	15.0	11.5	Do.
			'C' Quartzite		
62.	2.62	1.6	18.3	23.0	
63a.	2.59	0.6	25.4	25.2	
63b.	2.65	0.4	24.0	18.5	
63c.	2.65	0.5	25.3	20.5	
63d.	2.62	0.6	28.9	29.7	Leached, pink colour
63e.	2.62	0.5	28.7	29.6	Grey, leached
63f.	2.61	0.4	25.7	21.4	
63g.	2.60	0.7	23.1	19.8	
64.	2.60	0.6	21.8	17.8	
65.	2.56	2.0	31.5	33.1	Micaceous
66.	2.78	0.5	24.7	23.6	
67.	NO		TEST		

TABLE 1 (*contd.*)

S. No.	Specific gravity Bulk S.S.D.	Absorption Per cent	Crushing value (I.S.)	Wear Per cent	Remarks
68.	2.65	0.4	19.7	15.1	
69.	2.70	0.6	15.3	10.3	
70.	2.68	0.2	23.7	25.8	
			'D' Charnockite		
71.	3.10	1.0	25.6	28.8	
72.	2.78	0.2	19.1	14.2	
73.	2.75	0.3	20.3	13.5	
74.	2.83	0.3	19.6	17.6	
75.	2.79	0.3	19.4	14.5	
76.	2.75	0.2	22.7	14.0	
77.	2.71	0.2	22.2	14.9	
78.	2.68	0.2	21.2	16.0	
79.	2.69	0.4	21.4	16.1	
80.	2.73	0.3	22.2	13.7	
81.	2.92	0.2	18.9	14.1	
82.	2.68	0.2	22.4	16.3	
83.	3.00	0.3	23.5	18.3	
			'E' Limestone		
84a.	2.71	0.3	24.7	16.0	
84b.	2.73	1.8	23.0	14.4	
84c.	2.76	0.9	20.2	11.9	
85.	2.80	0.4	22.9	19.4	
86.	2.75	0.8	24.8	15.5	
87.	2.65	1.3	15.0	18.2	
88.	NO		TEST		
			'F' Sandstone		
89.	2.72	0.8	18.8	16.4	
90.	2.96	0.9	5.7	7.6	Rounded
91.	2.59	1.0	21.3	17.4	
92.	2.62	1.4	27.6	31.9	Light violet colour.

TABLE 1 (*contd.*)

S. No.	Specific gravity Bulk S.S.D.	Absorption Per cent	Crushing value (I.S.)	Wear Per cent	Remarks
93.	NO		TEST		
94a.	2.65	0.3	16.6	13.3	
94b.	2.60	0.4	24.2	20.1	
95.	2.85	0.5	15.2	11.5	
			'G' River Shingle		
96.	2.90	0.8	15.4	9.1	Rounded, smooth (Trap)
97.	2.68	0.8	18.4	16.2	„ (Quartzite)
98.	2.67	0.9	23.6	22.7	„ (Pitted and weathered)
			'H' Laterite		
99.	2.81	5.5	40.3	33.8	

ROAD AGGREGATES NOT TESTED

(1) Insufficient Quantity :

Samples from :

Pudukkottai,	Madras
Attur West	do.
Madurantakam	do.
Satna,	Bombay
Kheralu	do.
Ahwa	do.
Chalisgaon	do.
Akola	do.
Guntur,	Andhra Pradesh
Seraikella,	Bihar
Durg,	Madhya Pradesh
Darjeeling,	West Bengal

(2) Mixtures :

Samples from :

Kandaghat,	Madhya Pradesh
Vijayawada,	Andhra Pradesh
Adoni	do.

TABLE 2

Results of Adhesion Tests

Type of Aggregates

S. No.	Source	Quarry	Per cent Stripping	
			80/100 bitumen	R.T. Grade 3
		'A' Trap		
1.	Nagpur, Bombay	Boregaon	Nil	Nil
2a.	Bhuj, Bombay	Asambia, M. 23, Bhuj-Mandvi Road	5	5
2b.	Bhuj, Bombay	Viri, 2 M., South of Anjar	Nil	Nil
3.	Dakor, Bombay	Sevalia, 1 M. from Sevalia Station	Do.	Do.
4.	Khamgaon, Bombay	M. 31/5, Akola-Khamgaon Road	Do.	Do.
5.	Himmatnagar, Andhra Pradesh	—	Do.	Do.
6.	Akola, Bombay	—	Do.	Do.
7.	Panwel, Bombay	M. 44/7, Bombay-Poona Road	25	Do.
8.	Malikapur, Madhya Pradesh	—	Nil	Do.
9.	Dhandhuka, Bombay	—	Do.	Do.
10.	Murtizapur, Madhya Pradesh	—	Do.	Do.
11.	Khamgaon, Bombay	—	Do.	Do.
12.	Sevalia, Bombay	Sevalia P.W.D.	Do.	Do.
13.	Navasari, Bombay	—	Do.	Do.
14.	Surat, Bombay	—	Do.	Do.
15.	Amravati, Bombay	—	Do.	Do.
16.	Thana, Bombay	Bhandrup, M. 19, Bombay-Agra Road	Do.	Do.
16a.	Bhiwandi, Bombay	—	Do.	Do.
17.	Cuddapah, Andhra Pradesh	M. 5/2, Yerraghusla-Vempalli Road	Do.	Do.
18.	Baroda, Bombay	Devriver	Do.	Do.
19.	Nirmal, Andhra Pradesh	Mahboobghat, M. 140/144	Do.	Do.
20.	Amreli, Bombay	—	Do.	Do.
21.	Poona, Bombay	M. 19 and 37, Poona-Nagar Road	Do.	Do.
22.	Morvi, Bombay	Daladi	Do.	Do.

TABLE 2 (*contd.*)

S. No.	Source	Quarry	Per cent Stripping	
			80/100 bitu-men	R.T. Grade 3
23a.	Naldurg, Bombay	—	Nil	Nil
23b.	Naldurg, Bombay	—	Do.	Do.
24a.	Gondal, Bombay	4 M. from Gondal in N.H. 8-B.	Do.	Do.
24b.	Gondal, Bombay		Do.	Do.
25.	Netrang, Bombay	Near Arethi Village	Do.	Do.
26.	Dohat, Bombay	—	Do.	Do.
27.	Godhra, Bombay	Timba, Bank of Mahi River	Do.	Do.
28.	Bhusawal, Bombay	Kandari, Bank of Tapti River	Do.	Do.
29.	Dalim, Bombay	M. 129/3, N.H. 9, Osmanabad District	Do.	Do.
30.	Kallapardi, Bombay	—	Do.	Do.
31.	Pakur, Bombay	Lilatalab, 2 M. from Pakur Railway Station	Do.	Do.
32.	Jamtara, Bihar	Nutandih	Do.	Do.
33.	Sokdel, Madhya Pradesh	Goparu, M. 85/0, Rewa-Shahdol Road	Do.	Do.
34.	Ambikapur, Madhya Pradesh	Luchki, M. 3/5, Ambikapur-Pathalgaon Road	Do.	Do.
35a.	Dadri, East Punjab	Kalyana	Do.	Do.
35b.	Dadri, East Punjab	Kalyana	Do.	5
	'B' Granite			
36.	Simla, Himachal Pradesh	—	15	5
37.	Kangayam, Madras	Sivamalai	40	70
38a.	Kandi, Andhra Pradesh	Bandlaguda, M. 20/4, Hyderabad-Sholapur Road	30	10
38b.	Kandi, Andra Pradesh	Do.	20	15
39a.	Karimnagar, Andhra Pradesh	Do.	15	20
39b.	Karminagar, Andhra Pradesh	Do.	0	5
40.	Kawali, Andhra Pradesh	Gadhin	15	10
41.	Madanapalli, Andhra Pradesh	M. 158/1, Madras-Bombay Road	25	50
42	West Chittoor, Andhra Pradesh	Vangapalli, M. 99/8, Madras-Chittoor-Bangalore Road	15	15

TABLE 2 (*contd.*)

S. No.	Source	Quarry	Per cent Stripping	
			80/100 bitu-men	R.T. Grade 3
42a.	Chittoor, Andhra Pradesh	Annaswami Palli	20	25
43.	Dhamtari, Madhya Pradesh	—	30	10
44a.	Hyderabad, Andhra Pradesh	—	10	20
44b.	Hyderabad, Andhra Pradesh	—	35	60
45.	Dhone, Andhra Pradesh	M. 25/1, Benares-Cape Comorin Road	15	20
46.	Sullurpetta, Andhra Pradesh	—	5	15
47a.	Bhiwani, East Punjab	Khanak	10	25
47b.	Bhiwani, East Punjab		10	25
47c.	Bhiwani, East Punjab		Nil	Nil
48.	Nellore West, Andhra Pradesh	—	Do.	Do.
49a.	Kanigiri, Andhra Pradesh	—	Do.	10
49b.	Kanigiri, Andhra Pradesh	—	5	20
50.	Bhongir, Andhra Pradesh	—	10	30
51.	Gudur, Andhra Pradesh	Patriguntam, M. 77/4, Madras-Calcutta Road	Nil	5
52.	Bangarapet, Mysore	—	Do.	Nil
53.	Khammameth, Andhra Pradesh	—	Do.	10
54.	Tumkur, Mysore	Siddaganga, M. 5 from Tumkur, N.H. No. 4.	5	10
55.	Bhongir, Andhra Pradesh	—	Nil	Nil
56.	Jangaon, Andhra Pradesh	M. 49/7, Hyderabad-Hanamkonda Road	40	25
57.	Kazipet, Andhra Pradesh	—	30	90
58a.	Darjeeling, West Bengal	—	Nil	30
58b.	Darjeeling, West Bengal	—	Do.	50
58c.	Darjeeling, West Bengal	—	5	50
59.	Haliyal, Mysore	—	Nil	Nil
60.	Dharwar, Mysore	—	Do.	Do.
61.	Hubli, Mysore	—	5	20
	'C' Quartzite			
62.	Nargund, Mysore	Nargund Hill	10	5
63a.	Dadri, East Punjab	Kapuri	10	15
63b.	Dadri, East Punjab	Kapuri	Nil	25
63c.	Dadri, East Punjab	Adalpur	25	50

TABLE 2 (*contd.*)

S. No.	Source	Quarry	Per cent Stripping 80/100 bitumen	Per cent Stripping R.T. Grade 3
63d.	Dadri, East Punjab	Adalpur	15	5
63e.	Dadri, East Punjab	Khudana	40	Nil
63f.	Dadri, East Punjab	Khudana	10	Do.
63g.	Dadri, East Punjab	Kalyan	30	Do.
64.	Cuddaph, Andhra Pradesh	M. 118/6, Nellore-Bombay Rd.	Nil	5
65.	Nuzvid, Andhra Pradesh	—	5	Nil
66.	Kanke, Bihar	Kanke, M. 7 from Ranchi	15	Do.
67.	Walajabad, Madras	Kovalukkad	Nil	25
68.	Baria, Bombay	—	15	50
69.	Ranchi, Bihar	Bania Thesa, M. 128/1, Simdiga-Birmitrapur Road	15	Nil
70.	Delhi, Delhi	Badarpur	Nil	Do.
	'D' Charnockite			
71.	Kawali, Andhra Pradesh	—	Do.	Do.
72.	Tholudur, Madras	Veppur, M. 137, Madras-Trichy Road	5	Do.
73.	Madras North, Madras	Lihile Royapuram, 15 M. from Madras	Nil	Do.
74.	Madras, Madras	—	Do.	Do.
75.	Namakkal, Madras	Goolipally	Do.	Do.
76.	Walajabad, Madras	Kunnavakkam and Pattumalai	Do.	Do.
77.	Thirukalikundram, Madras	Thirukalikundram	Do.	5
78.	Acharapakkam, Madras	Pallipettai	Do.	Nil
79.	Walajabad, Madras	—	Do.	Do.
80.	Dumka, Bihar	Pasabhal	Do.	Do.
81.	Coonoor, Madras	M. 9/6, Ooty-Mettupalayam Road.	Do.	10
82.	Chinglepet, Madras	—	Do.	Nil
83.	Daltonganj, Bihar	—	Do.	Do.
	'E' Limestone			
84a.	Rewa, Madhya Pradesh	Kalihai	5	20
84b.	Rewa, Madhya Pradesh	Saman	Nil	10

TABLE 2 (*contd.*)

S. No.	Source	Quarry	Per cent Stripping 80/100 bitumen	Per cent Stripping R.T. Grade 3
84c.	Rewa, Madhya Pradesh	Ramnai	Do.	Nil
85.	Simla, Himachal Pradesh	—	Do.	70
86.	Raipur, Madhya Pradesh	Rajun	Do.	5
87.	Bhiwani, East Punjab	—	Do.	5
88.	Durg, Madhya Pradesh	—	Do.	Nil
	'F' Sandstone			
89.	Simla, Himachal Pradesh	Sanjauli, M. 5 from Simla	10	Do.
90.	Bhind, Bombay	—	Nil	Do.
91.	Kotah, Rajasthan	—	Do.	Do.
92.	Dhamtari, Madhya Pradesh	—	20	Do.
93.	Durg, Madhya Pradesh	—	Nil	Do.
94a.	Chinthala, Andhra Pradesh	M. 86/1 Kurnool-Guntur Road	Do.	Do.
94b.	Chinthala, Andhra Pradesh	M. 5/8, Dornal-Srisailam Road	Do.	Do.
95.	Palanpur, Rajasthan	Chitrasani and Amirgadh	Do.	Do.
	'G' River Shingle			
96.	Khamgaon, Bombay	M. 7, Khamgon-Nander Road	Do.	Do.
97.	Dharamshala, E. Punjab	—	Do.	Do.
98.	Silliguri, Bihar	Mahananda & Kalihara River	Do.	Do.
	'H' Laterite			
99.	Malidhar, (Cachar) Assam	—	Do.	Do.

ROAD AGGREGATES NOT TESTED

(1) **Insufficient Quantity**

Samples from:

Pudukkottai,	Madras
Attur West,	Madras
Madurantakam,	Madras
Satna,	Bombay
Kheralu,	Bombay
Ahwa,	Bombay
Chalisgaon,	Bombay
Guntur,	Andhra Pradesh
Seraikella,	Bihar

(2) **Mixtures:**

Samples from:

Kandaghat,	Madhya Pradesh
Vijayawada,	Andhra Pradesh
Adoni,	Andhra Pradesh

3. NATURE OF TEST SAMPLES

3.1. The road aggregates received are classified into seven main groups, viz., trap, granite, quartzite, charnockite, sandstone, limestone and river-shingle. One laterite sample was received from Assam. The aggregate size in most of the samples varied from 2 to 6 in., hence, had to be broken afresh to the required sizes, while, those received in broken state were used as received if of the required sizes. The river-shingles, round and smooth, were tested without breaking the same.

3.2. The sizes of road stone which are commonly employed for surface dressing and open premix carpet are standard $\frac{3}{4}$ in. and $\frac{1}{4}$ in. However, under identical conditions of testing stripping is more as the size decreases, mainly because the smaller sizes in most stones are flaky with sharp edges. Further, it is found that nearly all the natural stones are weaker in the larger sizes and, therefore, give higher aggregate crushing value than the smaller sizes of the same material (I.S. 383—1952). Therefore, for the various physical tests such as Los Angeles Abrasion test (3/4 in. to $\frac{1}{2}$ in. and $\frac{1}{2}$ in. to 3/8 in.); Aggregate Crushing test ($\frac{1}{2}$ in. to 3/8 in.); Static Water Immersion test (1 in. to $\frac{1}{2}$ in.) and Specific Gravity and Absorption test (1 in. to 3/8 in.) were used. The sizes of the aggregates were so chosen that they represent as far as possible the size usually used in surfacing of roads.

3.3. For the stripping test, the aggregates are not washed so as to simulate field condition, where the stones are probably never washed. It is however desirable that there should not be any dust coating on the aggregates; and that the maximum amount of dust on loose dry aggregate for black top should not exceed 2 per cent by weight of the aggregates[10]. Washing of the aggregates should be done in case of excessive amount of dust especially in the form of coating on the aggregate.

3.4. The binders usually used for surface dressing and open premix carpet are Road Tar Grade 3 and bitumen 80/100 penetration. For premix work with bitumen, the aggregates were heated to a temperature of 280—300°F. Prior to coating with the binder heated up to 350°F. Under these conditions any question about the presence of moisture in the aggregates does not arise. In surface dressing work where the aggregates are spread over the hot binder sprayed on the prepared road bed, the initial moisture in the aggregates plays an important part, especially as far as stripping is concerned. It is well-known that the affinity between stone and water is better than that between stone and binder and as such the higher the moisture, the lower the ability of the binder to coat the aggregate. However, when the aggregates are wet, some of the

adhesive agents could very usefully be employed for the proper adhesion of binder with the wet stone surface.

3.5. When Road Tar Grade 3, used for the stripping test was heated to 225°F. and mixed with the aggregates kept in an oven at 100°F. for an hour, it was found difficult to coat the aggregates well at atmospheric temperature. Even under these conditions it was found that for perfect coating, effected in the laboratory, the mixing took about two minutes over a flame.

4. PHYSICAL PROPERTIES OF THE AGGREGATES

4.1. Standard specifications are available for road aggregates according to ASTM, B.S. or I.S. Among the common general physical characteristics may be mentioned that all aggregates shall be clean, tough, durable, free of thin or elongated, soft or disintegrated pieces, and shall not be coated with dirt or other objectionable matter. Crushed gravel shall consist of fragments having two or more fractured surfaces. Crushed slag shall be aircooled blast-furnace slag with minimum compacted unit weight of 70 lb per cu. ft.

4.2.1. According to ASTM designation, D1139—55T[4] the maximum per cent wear in Los Angeles Abrasion test can be 40 for aggregates used for single or multiple surface treatments. For coarse aggregates in bituminous concrete base and surface courses, it is given that the coarse aggregate for the base coat shall not have Los Angeles Abrasions test value exceeding 40 per cent that for the sub-base course not exceeding 50 per cent, shall not lose weight exceeding 12 to 18 per cent when subjected to five cycles of the soundness tests using sodium sulphate and magnesium sulphate. According to the Indian Standard[6] (I.S. 383—1952) the important tests to be carried out on the mineral aggregates are specific gravity, water absorption, soundness, crushing and abrasion tests. It is stated in Research Notes No. RN/3531 of Road Research Laboratory[7], that in the new British Standard (revised B.S. 812—1951) aggregate tests include ten per cent Fines test and Accelerated Polishing test in addition to the specific gravity, water absorption, crushing, impact or abrasion, etc. The Deval Attrition test, Dorry Abrasion test and Page Impact tests, etc., most widely used tests for road stones in the past are seldom used now. British Standard Specifications for road-making materials and processes apart from grading and shape rarely specify for universal application limits to the physical properties of aggregates.

4.2.2. In a specification under consideration of the Indian Roads Congress[8] for single coat bituminous surface dressing, the following limits are being considered for the physical standards of the road aggregates.

Per cent wear max., Los Angeles Abrasion Test ...		40
Aggregates crushing value, max. ...		30
Flakiness Index, max. ...		25
Per cent stripping (area exposed) max. (Static Water Immersion Test, CRRI)		25
Soundness test, Per cent loss in weight in 5 cycles, max.	Na_2SO_4 12	$MgSO_4$ 18

4.3. Surface textures of aggregates may be classified as glossy, smooth, granular, crystalline fine, medium and coarse, pitted, honey-combed and porous. Of these, for adhesion with binder, crystalline texture from fine to medium was found to be quite suitable. Typical examples of surface textures of the road stones studied are given in Photos 1 to 8.

4.4. Different particle shapes came across were rounded, irregular, angular and flaky. Though rounded and smooth particles can be easily coated with binder it was found that when stripping starts, the binder film peels off more easily. As the rounded aggreggtes get more easily dislodged by traffic than the crushed stones, they should preferably be used in a crushed form having two or more fractured surfaces or containing at least 60 per cent of fractured particles.

For minimum stripping, irregularly shaped aggregate is preferable because with angular stones having well-defined sharp edges there are chances for the edges to remain uncoated. Moreover in the case of flaky pieces there is the additional drawback of their easily getting crushed under traffic.

4.5.1. Though several standard specifications for the physical properties of the road aggregate are laid, its most important properties for bituminous pavement are resistance to abrasion, crushing, stripping, specific gravity and water absorption. Soundness test is of importance for aggregates used in surface dressing. The water absorption value of aggregates can be taken as an index of the resistance to frost action. Water absorption value exceeding 1.5 can be harmful where the aggregates are likely to be subjected to freezing and thawing. Brief details of the physical tests conducted on the different types of aggregates received are given below and test results are given in Table 1.

4.5.2. **The Specific Gravity and Absorption of Aggregates : I.S : 383-1952**[6]: For this test, aggregate of 1 in. to 3/8 in. size is used.

Photo 1

Photo 2

Photo 3

Photo 4

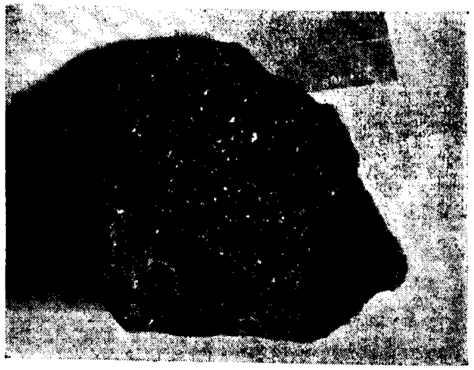

Photo 7

Photo 5

Photo 8

Photo 6

Photo 9

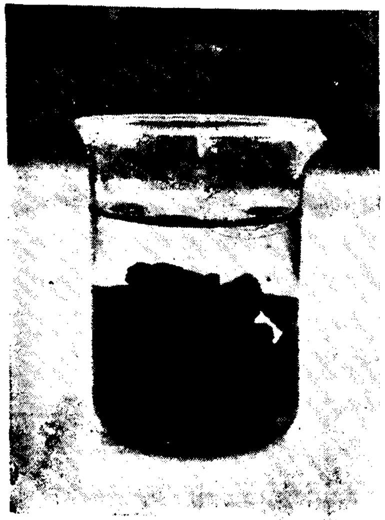

Photo 10

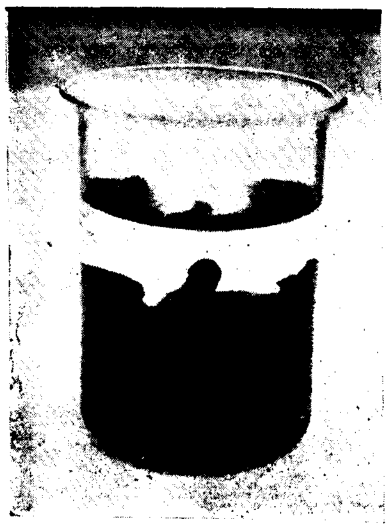

Photo 11

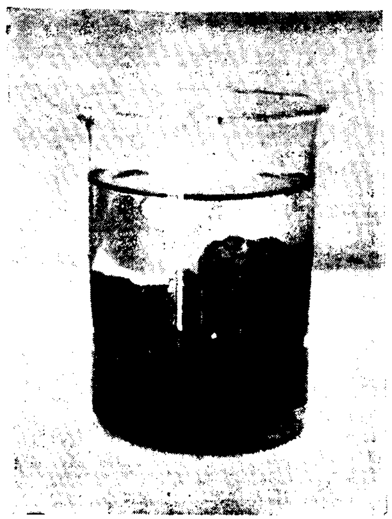

Photo 12

The bulk specific gravity on a saturated surface dry basis is given along with the percentage of water absorption of the aggregate.

4.5.3. **Aggregate Crushing Test : I.S : 383-1952**[6]: For this test 1/2 in. to 3/8 in. aggregate is used with total applied load of 40 tons, mean of the observation of two tests was taken as the aggregate crushing value, (the percentage of the total sample weight, of fines passing No. 240 I.S test sieve or No. 7 B.S Sieve).

4.5.4. **Abrasion of Coarse Aggregate : I.S : 383-1952**[6]: In this test grading 'B' 2500 grams each of 3/4 in. to 1/2 in. and 1/2 in. to 3/8 in. aggregate was used with an abrasive charge consisting of 11 steel spheres weighing 4584 ± 25 grams. After 500 revolutions the difference between the original weight and the final weight of the sample retained on No. 170 I.S sieve (No. 12 ASTM sieve) is expressed as a percentage of the original weight of the sample and reported as the per cent wear. Duplicate tests were carried out for confirmation.

5. ADHESION WITH BINDERS

5.1. Details of studies dealing with the principles of adhesion, factors involved in the adhesion of binder to stone, methods for estimating stripping as well as standardisation of a qualitative test to suit conditions prevailing in India are given in Road Research Papers No. 14 and No. 18 of Central Road Research Institute and published in the Journal of the Indian Roads Congress. [9, 10]

5.2. The failure of a bituminous surfacing due to stripping of binder from the freshly coated aggregate by water is more pronounced and wide spread in open textured surfaces such as single sized premix carpets or surface dressing than in dense graded mixtures. The size of the aggregate in the test for adhesion was 1 in. to 1/2 in. only; smaller sizes were discarded because information regarding stripping characteristics of the finer fractions is not always applicable to the behaviour of the coarser aggregates of the same stone for the reasons already mentioned in paras 3.2 and 4.4.

5.3. The test procedure adopted for the Static Water Immersion test consisted of coating the aggregate of 1 in. to ½ in. with 5 per cent by weight of the binder ; the mixing was done as specified for the binder ; curing for 2 hours at atmospheric temperature and keeping the sample immersed in distilled water at 40°C. for 24 hours. The extent of stripping is estimated after this period. A maximum of 15 to 20 per cent of stripping by this method is stipulated for successful performance of the surfacing. Aggregates with stripping upto 5 per cent only may be considered as good ; 5 to 20 per cent as satisfactory and above that as poor. Typical examples showing good, satisfactory and poor adhesion are given in Photos 10 to 12. Test results for the various samples are given in Table 2.

5.4. In an article in 'Crushed Stone Journal' June 1959[11] it is given that "in a Static Immersion Test" using cutback asphalt the percentage of aggregate remaining coated should be 95, that is, a stripping of 5 per cent only (AASHO Designation T-182-57) but, in some laboratories the asphalt is considered to have stripped excessively only if the area remaining coated is below 70 per cent, that is, stripping of more than 30 per cent."

6. PETROLOGICAL EXAMINATION

6.1. "The usual physical tests carried out to assess the suitability of road aggregates disclose very little with respect to the fundamental properties; they reflect only behaviour under particular test conditions, however intrinsic properties of aggregates are obtainable through the discerning application of the principles and methods of petrography."[12]

6.2. Hence, the petrological examination of road aggregates has been made with a view to study as to how far it can explain the phenomenon of adhesion between binder and stone and whether it can forecast the behaviour of the coated stone. The study includes the following tests.[13] (a) Petrological nomenclature; (b) Trade group; (c) Mineralogical composition; (d) Average grain size; (e) Decomposition factor; (f) Micro texture. The petrological analysis is conducted with the help of the Leitz Integrating Stage and Leitz Polarising Microscope as shown in Photo 9.

6.3. In general, road aggegates received fall under the following four geological categories, viz., (1) Igneous, (2) Sedimentary, (3) Metamorphic, (4) Volcanic. Their use is found in conformity with the geological formation[14] as shown in Table 3. In all, the mineral road aggregates are classified into 7 groups given below:

Type	Trade group	Category
1. Deccan Traps and Dolerites	Basalt	Volcanic
2. Granites, Gneisses, Schists, and Granodiorites.	Granite	Igneous
3. Charnockites		
4. Quartzites	Gabbro	Do.
5. Sandstones	Quartzite	Metamorphic
6, Limestones	Grit stone	Sedimentary
7. River-Shingles	Limestone	,,

TABLE 3

Geological Formations of India

No.	System	Rock types predominant	Provinces in which the rock type is dominant
1	Archaen	Granites, gneisses, schists, charnockites, intrusive rocks, quartzites	1. Andhra, 2. Mysore, 3. Madras, 4. Kerala, 5. Bihar, 6. Assam, 7. Madhya Pradesh
2.	Dharwar	Gneisses, schists, slates, marbles, quartzites	1. Mysore, 2. Bihar, 3. Assam, 4. Orissa, 5. Bombay
3.	Cuddaph	Limestones, marbles, sandstones, schists, dolomites, phyllites	1. Rajasthan, 2. Andhra, 3. Madhya Pradesh
4.	Vindhyan	Sandstones, limestones, shales	1. Rajastan, 2. Madhya Pradesh, 3. Andhra
5.	Gondwana	Sandstones, shales, clay and coal	1. West Bengal, 2. Bihar, 3. Bombay, 4. Andhra, 5. Madhya Pradesh
6.	Cretaceous	Sandstones, shales, clays and limestones	1. Madras, 2. Bombay, 3. Assam
7.	Deccan traps	Trap rock, basalt, dolerite, chalcedony ,etc.	1. Bombay, 2. Madhya Pradesh
8.	Tertiary	Oil-bearing sandstones and limestones with intrusions of granites	Mainly extra peninsula and Assam

TABLE 4-A

Relation between Petrological Properties of Roadstones and their Adhesion with Bituminous Binders

No.	S. No.	Locality	Rock type	P. F.	P. L. F.	Q.	M. M.	M. F.	P.	G.	Average grain size	Surface texture	ADHESION 80/100 Bitumen	ADHESION Road Tar Grade RT-3	Remarks
1	44b	Hyderabad	Granite	34.69	13.53	42.89	7.00	1.94	—	—	Coarse	Coarsely Cry.	Poor	Poor	1. P.F. = Potash feldspar
2	56	Jangaon	Granodiorite	20.23	22.50	48.2	7.10	1.95	—	—	Do.	Do.	Do.	Do.	2. P.L.F. = Plagioclase feldspar
3	37	Kangayam	Do.	1.28	48.30	47.00	2.10	0.40	—	—	Do.	Do.	Do.	Do.	
4	57	Kazipet	Granite	65.88	2.55	32.05	0.05	—	—	—	Do.	Do.	Do.	Do.	3. Q = Quartz
5	41	Madanapalli	Do.	58.39	8.77	22.98	4.59	5.38	—	—	Do.	Do.	Do.	Do.	4. M.M. = Micaceous minerals
6	46	Sullurpetta	Do.	35.32	13.79	43.56	5.49	1.80	—	—	Medium	Medium Cry.	Satisfactory	Satisfactory	5. M.F. = Mafic minerals
7	48	Nellore West	Do.	35.29	5.35	48.59	6.15	2.96	1.66	—	Do.	Do.	Do.	Do.	6. P = Perthite
8	55	Bhongir	Do.	34.34	10.24	36.68	4.51	1.27	12.93	—	Do.	Do.	Good	Do.	7. G = Garnetes
9	54	Tumkur	Do.	32.75	9.38	52.03	3.60	1.14	0.83	—	Do.	Do.	Satisfactory	Do.	8. Cry. = Crystalline
10	77	Thirukalikundram	Charnockite	0.86	28.11	59.80	0.58	10.43	—	—	Coarse	Coarsely Cry.	Good	Good	
11	79	Walajabad	Do.	4.30	37.20	49.05	1.24	8.19	—	—	Do.	Do.	Do.	Do.	
12	81	Coonoor	Do.	4.86	21.50	62.04	0.02	11.34	—	0.83	Do.	Do.	Do.	Do.	
13	83	Daltonganj	Do.	—	22.41	25.99	0.17	51.41	—	0.92	Fine	Finely Cry.	Do.	Do.	
14	72	Tholudur	Gneiss	5.52	15.06	49.01	20.27	4.03	—	6.08	Medium	Medium Cry.	Do.	Do.	
15	73	Madras N.	Charnockite	15.70	23.49	44.38	0.62	16.38	—	0.01	Do.	Do.	Do.	Do.	
16	1	Nagpur	Deccan trap	—	45.00	3.00	—	52.00	—	—	Fine	Finely Cry.	Do.	Do.	
17	4	Khamgaon	Do.	1.12	48.89	4.50	—	45.70	—	—	Do.	Do.	Do.	Do.	

pact than sandstones. They are found to vary in colour from sample to samples; occurring in grey, pink, blue, violet and flesh colours. This may be due to the leaching and weathering of iron contents in the rock. They have been found to vary in grain size from coarse to medium and fine grained. Small quantities of mica are found in most of the quartzite samples examined microscopically. Though acidic in nature some quartzites are found to have good adhesion with bituminous binders, especially in the medium and fine grained in types.

6.8. Sandstones are also monomineralic like quartzites and mainly contain quartz grains cemented by silicious or calcarious materials. In most of the sandstones, the shape of the quartz grain is angular to sub-angular, and the grain size varying from coarse to medium and fine. With coarse grained sandstones there is likelihood of stripping of binder.

6.9. Most of the limestones that are subjected to petrological study are either dolomitic in nature or are purely calcitic ones. They vary in colour from white to grey and black. They are mainly fine grained and have smooth surface texture.

6.10. River-shingles, round and smooth, tested are derived from trap, sandstones or quartzite.

6.11. The only laterite sample received from Cachar is quite compact and free from weathering which is evident from its high specific gravity of 2.84.

Actual physical tests rather than petrological data should be made use of in the selection of laterite as a road stone.

7. DISCUSSION

7.1. The number of samples tested from each of the seven groups of mineral aggregates give an approximate idea of the extent of their use as road aggregates in India. As some States have not sent any samples, and some have sent only a few, a fair generalisation cannot be made about their nature and use in the whole country.

7.2. From the physical properties such as specific gravity, absorption, crushing value and abrasive resistance of the various road aggregates tested, it is found that nearly all the samples come within the specified limits and thus satisfy the requirements for their use as good road stones. The average specific gravity varies from 2.64 to 2.95, the lowest for quartzite and highest for trap, while the absorption varies from 0.3 per cent for charnockite to 1 per cent for trap as given in Table 5. Usually when the water

TABLE 5

Results of Physical Tests on the various Types of Road Aggregates (Average and Range)

No.	Type	Specific gravity Bulk S.S.D.		Absorption of water Per cent		Crushing value I.S.		Per cent wear, Los Angeles Abrasion		No. of samples	
		Average	Range	Average	Range	Average	Range	Average	Range	Average	Range
1	Traps	2.95	2.71—3.36	1.0	0.3—5.2	17.0	11.2—27.8	11.0	7.5—23.9	37	39
2	Granites	2.67	2.61—2.76	0.5	0.2—1.3	25.0	15.0—32.5	20.0	11.5—35.4	29	29
3	Quartzites	2.64	2.56—2.78	0.6	0.2—2.0	23.0	15.3—31.5	22.0	10.3—33.1	13	14
4	Charnockites	2.76	2.68—3.10	0.3	0.2—1.0	21.0	18.9—25.6	15.0	13.5—28.8	12	13
5	Limestones	2.73	2.65—2.80	0.9	0.3—1.8	22.0	15.0—24.8	16.0	11.9—19.4	6	6
6	Sandstones	2.67	2.60—2.96	0.7	0.3—1.4	21.0	5.7—27.6	18.0	7.6—31.9	6	7
7*	River-shingles	2.75	2.67—2.90	0.8	0.8—0.9	19.0	15.4—23.6	16.0	9.1—22.7	3	3

* Belong to different trade groups—*vide* Table 1

absorption is above $2\frac{1}{2}$ per cent, the bulk impregnated specific gravity is adopted so as to allow for the absorption of bituminous binder by such aggregates.

7.3. The high specific gravity of traps may be due to the presence of ferro magnesium minerals in large quantites, so is the case of charnockites, the bulk minerals in granites, sandstones and quartzites are quartz, feldspar etc., which are of low specific gravities. Absorption of water by traps is comparatively higher due to the vesicular structure, for example, the trap samples from Panwel (No. 7), Nirmal (No. 19) and Akola (No. 6) show 5.2 per cent, 3.3 per cent and 2.3 per cent absorption respectively and is clearly indicated by the dull or brownish look instead of a black glossy appearance when coated with bitumen.

7.4. It is evident from Table 5, that trap has the lowest crushing value followed by the river-shingle, while, sandstone, charnockite and limestone have a value around 21 and granite and quartzite around 24. A high crushing value indicates the inferior quality of the aggregate. The low value for trap can be attributed to it's ophitic texture and presence of tough minerals like pigmatite, augite, etc. Crushing value of some granites and quartzites are quite near or beyond the maximum of 30 specified, it would be seen from Table I that in all those cases the high values are due to weathering, alteration in the bulk minerals or fissuring. The specific gravities in those cases are also comparatively lower than others of the same group. The wear due to abrasion is also very high for the samples with high crushing values. The only laterite sample tested has a crushing value of 40 and hence, unsuitable based on the maximum of 30 specified, though its per cent wear is only 34, well below the maximum of 40 stipulated.

7.5.1. The most satisfactory aggregate tests are those which simulate as closely as possible the condition of service required of the aggregate. "From the 'laboratory roller test' Goldbeck has concluded that the Los Angeles Test does agree exceptionally well with service behaviour. The results of the test are of value as indications of aggregate break down under rollers and wheel-loads in traffic, in the case of water bound, or low type bituminous surfacing."[18]

7.5.2. Quite in agreement with the crushing value the traps are found to have the lowest wear values, while, the granites and quartzites have comparatively higher wear value. The average wear values for the charnockites, limestones and sandstones are between 15 and 18.

7.5.3. As laid down in B.S. 812-1951[19], 1/2 to 3/8 in. size aggregate, was used for the standard crushing test, "the results show close numerical agreement with those of the Los Angeles test. Very soft aggregates tend to give lower results on the aggregates crushing test than on the Los Angeles Abrasion test. Larger sizes than 1/2 to 3/8 in. give a higher aggregate crushing value, and smaller sizes a lower value; the relations between values obtained with different sizes vary according to the property of the aggregate."

7.5.4. From the crushing tests and abrasion tests of various road aggregates, it is seen that with 1/2 to 3/8 in. size aggregate used in the standard aggregate crushing test and aggregate grading 'B' in the Los Angeles Abrasion test, the test results do not show numerical agreement; but, they are comparable, viz., the higher the crushing value the higher the per cent wear and vice versa. Except in a very few cases, the wear values are quite lower than the corresponding crushing values. However, when the wear values are pretty high, they agree more or less with the crushing values.

7.5.5. In none of the roadstones tested the wear values are above the maximum of 40 specified, while, there are a few cases where the crushing values are quite near or above the maximum of 30. Hence, the rejection of an aggregate should be decided from the results of both the crushing test and the abrasion test. It also seems justified from the test results of the various road-stones that the limit of 30 for crushing value may be raised slightly. However more aggregates are to be tested to confirm this. The note given in ASTM Designation, D1139-55T and quoted below supports this view. "The requirement of physical properties of aggregates in these specifications are recommended as satisfactory requisites for quality. It is expected that these limits for quality will be varied in particular localities and will not be applicable under all conditions thereby permitting the use of local aggregates that will give satisfactory performance."

7.5.6. Above all, it should be remembered that in the selection of suitable aggregates for a road surfacing work, economy in cost should be given due importance. Hence, slight deviations from the physical requirements specified for an aggregate may be overlooked provided the cost and availability of the material justify it[3].

7.6. Though there can be adverse comments on the use of the qualitative test for the estimation of stripping based on visual examination, which naturally depends on the experience and judgement of the person concerned, it is possible to arrive at a resonable and reliable evaluation of the resistance to stripping of a particular combination of an aggregate and binder by this test. Another important criticism against this most simple and widely adopted qualitative test is that, since, it is a static test, it does not bring in the rigorous abrasive effect of traffic as in a road. The Wheel Tracking test developed at the Road Research Laboratory, London, for a quantitative estimation may in that respect be preferable but, for open premix carpets its estimation is difficult. There are many other methods for a quantitative estimation of stripping for which expensive equipments are required but even those do not simulate the field conditions and each has its own advantages or draw backs[20].

7.7.1. All the trap samples tested have quite good adhesion with tar and bitumen except one (No. 7), from Panwel, for which there was 25 per cent stripping when bitumen 80/100 was used. This trap was highly porous (absorption 5.2 per cent) and contained big crystals of pyrites (green) and zeolites (white) in the amygdaloidal cavities. All the zeolite crystals stripped completely due to zeolite being a hydrated mineral. According to 'Minty' poor adhesion is attributed to presence of hydrated minerals, within or on the surface of a rock[21]. Tar is the proper binder for this trap so far resistance to stripping is concerned. Samples No. 19 and 6 have high absorption and show good adhesion with bitumen and tar probably due to the presence of large crystals of secondary minerals occurring in the amygdaloidal cavities.

7.7.2. It has been observed by many workers that dolerite and basalt show very good adhesion with bituminous binders. High percentage of mafic minerals (ferromagnesium minerals) in trap in addition to the smooth surface texture and fine grain support the above finding as can be seen from Table 4-A.

7.8. Adhesion of binders, both bitumen and tar, with all the charnockite samples tested was quite good. Charnockites are richer in mafic content than the granites but contain smaller quantities of potash feldspar and micaceous minerals. These are the basic requirements for good adhesion with bitumen and tar. According to Prof. Shand,[22] an eminent geologist, "the presence of mica in a rock is an indication of excess of alumina in the rock". On that basis, he has differentiated granites as aluminous and charnockites as sub-aluminous. The mafic mineral content in charnockite plays a more important part as far as adhesion is concerned because some charnockites with as coarse a surface texture as some granites have not shown any stripping.

7.9.1. Of the 34 granite samples tested, 62 per cent have stripping below 20 per cent and 23 per cent of the total have stripping below 5 per cent. Considering the number of samples tested, granites have shown lower stripping resistance than quartzites due mainly to their coarsely crystalline surface texture. Only two samples have failed with bitumen while about 17 per cent have stripping above 20 per cent when tar is used. Bitumen should be used where stripping has taken place with tar and vice versa in cases where stripping is beyond the maximum specified. About 15 per cent of the granite samples have failed to withstand the test, either with tar or bitumen. Selection of suitable binders with higher viscosities depending on the time and type of construction can prevent stripping from such aggregates as shown in para 7.15.4.

7.9.2. It is to be noted that granites are essentially rich in potash and plagioclase feldspar, quartz and mica. Mafics, if at all present, are in a very minute quantity. The presence of micaceous minerals and deficiency of mafic minerals in granites in contrast with the charnockites is very important for their lower resistance to stripping. "Quartz, feldspar and mica, when occurring in large crystals in the granite, give poor surfaces for the adhesion of bitumen and tar[23]." But, it is seen that that medium to fine grained granites, gneisses and schists show satisfactory adhesion with bitumen and tar.

7.10.1. Among the 15 quartzites samples tested for stripping, it was found that in 10 of them (67 per cent) the extent of stripping using tar or bitumen as binders is below 20 per cent and hence, quite satisfactory. Out of these in three cases or 20 per cent of the total number tested it is below 5 per cent. Three samples from Dadri have failed with bitumen while one from Walajabad, quite coarse in surface texture, one from Baria as well as the bluish grey and pink varieties, both coarse, from Dadri have failed when tar is used. As mentioned in para 7.9.1 proper binder should be selected for the stones with low stripping resistance.

7.10.2. "In the monomineralic rocks like quartzites, sandstones, limestones, etc., the mineral content does not affect the aggregate characteristices as much as the structure. It is however an advantage for the predominant mineral to be as near as possible to the only one present[24]." Uniformity is however the main characteristic which affects the properties for their use in asphalt mixtures. The group of rocks which exhibit a crystalline surface texture of medium crystal size are found to have the most suitable faces for adhesion. The quartzite samples tested have been found to vary in grain size from coarse to medium and fine. The medium and fine grained quartzites are found to show good adhesion with bitumen and tar, while, in the case of coarse grained stripping took place; see Table 4-B.

7.11. Though quartz is the major constituent in the sandstones, stripping does not take place either with bitumen or tar, except in one sample from Dhamtari No. 92 due to its coarse grained and rough surface texture. Sample No. 92 stripped to the extent of 20 per cent with bitumen. In such a case tar can preferably be used as the binder.

7.12.1. Limestones are generally considered good as far as their resistance to stripping is concerned. Among the seven samples tested, one from Simla cannot be used with Road Tar Grade 3 due to the stripping being quite high, though bitumen 80/100 is found suitable. This is due to the coarse and non-uniform grain and some of the calcite grains occurring in quite large sizes as given in Table 4-B. Again, one sample from Rewa (Kalihari quarry) has also about 20 per cent stripping with Road Tar Grade 3. These limestones, when broken, have sharp edges and go into flakes and may have been responsible for stripping to start from the edges especially when a low viscosity binder is used.

7.12.2. "Medium to fine grained limestones with smooth surface texture provide good surfaces for adhesion. Where a high proportion of large crystals of calcite, either in the ground mass or as part of large fossils occurs, tendency to brittleness and poor adhesion with bitumen can be expected" [25]. P. A. Valton in his book 'Limestone Roads [26] concludes that the best varieties of limestones for use as road aggregates are the dense, medium, fine grained and crystalline types; free from veins, cracks and cavities.

7.13. River-shingles, though they have the drawback due to their smooth surface and round shape as given in para 4.4, are found to have quite good stripping resistance with both tar and bitumen as observed from the Static Water Immersion test.

7.14. The only laterite sample tested, which is quite compact, shows no stripping, either with tar or bitumen, due to the ferrogenous materials present in it to a great extent. But, it has a crushing value of 40 per cent, wear 34; both are too high for a good road stone. There is the further drawback that it is difficult to coat all the cavities, for which extra binder is required.

7.15.1. Illustrations showing the complicated adhesion characteristics between some stones and binders can be had from the stripping test results of quartzites with bitumen and tar, e.g., the samples No. 63e and 63g show no stripping with tar, while, with bitumen it is not so. Again 63b, 67 and 68 show poor adhesion with tar, while it is good with bitumen. Sample No. 63c at the same time has failed with both tar and bitumen. "Though tars due to their phenolic contents may be responsible for better adhesion with basic stones, phenol is of no special advantage when acidic rocks (like quartzites) are concerned [27]. This leads to the conclusion that actual laboratory tests should also be conducted to decide the suitability of the aggregate rather than judging it from the purely petrological data of the aggregate.

7.15.2. Based on the results of tests carried out at the Road Research Laboratory in Great Britain on a large number of aggregates, Hosking has also concluded that "Knowledge of the group to which a rock belongs does not permit its categorical rejection or acceptance as a road-making aggregate". Only tests on sample of the actual materials to be used can provide reliable information [28].

7.15.3. The importance of viscosity of binder on stripping needs to be emphasizd especially when coarse grained road aggregates, like granites, which have low stripping resistance are concerned as found in para 7.9.1. Table 6 shows 13 samples of coarse grained granite stones tested using bitumens 80/100, 60/70 and 30/40 and Road Tars Grade 3 and 4.

TABLE 6

Showing the Per cent of Stripping of some Granite Roadstones Tested with Different Binders

No.	S. No.	BINDERS USED				
		Bitumens			Tars	
		80/100	60/70	30/40	RT-3	RT-4
1.	37	50	15	Nil	90	30
2.	38a	30	—	—	10	—
3.	41	25	15	5	50	15
4.	43	30	—	—	10	—
5.	44b	35	15	—	60	25
6.	47a	10	—	—	25	—
7.	47b	10	—	—	25	—
8.	50	10	—	—	30	—
9.	56	40	20	5	25	15
10.	57	30	20	Nil	90	15
11.	58a	Nil	—	—	30	—
12.	58b	Nil	—	—	50	10
13.	58c	Nil	—	—	50	—

It is clearly seen that the extent of stripping with R.T. Grade 3 is far in excess of 80/100 bitumen, except in 3 cases, Nos. 38a, 43 and 56. The peculiar behaviour of these three granite samples is a further proof of the complicated phenomenon of adhesion, which is dependent on the aggregate, the binder or a combined effect of the two.

7.15.4. It is however seen that when the road stones of numbers 37, 41, 44_b, 56 and 57 which failed too severely with 80/100 bitumen and R.T. Grade 3 when subjected to the Static Water Immersion test with the more viscous binders like 60/70 and 30/40 bitumens and Road Tar Grade 4, the extent of stripping is reduced very much as seen from Table 6, thereby showing the resistance offered by higher viscous binders to their removal by water. With 30/40 bitumen there is practically no stripping even from the worst type of stones tested. When R.T. Grade 3 is replaced by R.T. Grade 4, the extent of stripping is further reduced appreciably.

Hence, it is but essential that when road stones such as the above are to be used, selection of a higher viscosity binder

than R.T. Grade 3 or 80/100 bitumen such as R.T. Grade 4 or 60/70 bitumen should be made depending on the time and type of construction, this will help to a great extent in solving the problem of stripping of binder from such stones.

7.15.5. The proper choice of an aggregate and binder for use in a black top mixture is not a panacea for all types of failures of the surfacings. Any deviation from the specifications laid for the proportioning, mixing and laying as well as poor workmanship and defective equipments used are other important factors which are responsible for the premature failure of a black top surfacing.

7.16. Based on the average values of results of physical tests as well as adhesion tests conducted, evaluation of the various types of road aggregates is made and is given in Table 7.

8. CONCLUSIONS

From the limited number of samples of road aggregates belonging to the different trade groups, more or less representing those used all over India for black top surfacings, the following general conclusions may be drawn, based on the physical properties, adhesion with bituminous binders and petrological analysis :

1. The average specific gravity of the various types of road aggregates varies from as low as 2.64 to as high as 2.95 and nearly all of them have crushing value and per cent wear within the limits specified for good road stones, that is, 30 and 40 respectively.

2. Roadstones belonging to the granite, gabbro and quartzite groups have an average water absorption of about 0.5 per cent compared to stones belonging to the basalt and limestone groups with a water absorption of about 1 per cent.

3. No close numerical agreement is found between the results of crushing tests and Los Angeles Abrasion test of the various aggregates. However, the wear values and crushing values tend to approach each other when wear values are high.

4. The suitability of road aggregates should be decided upon from both the aggregate crushing value and per cent wear in the Los Angeles Abrasion test.

5. Based on the Static Water Immersion test adopted for the evalution of stripping it can be said that adhesion between roadstones and bituminous binders in the presence of water depends on the aggregate, the binder or a combined effect of the two.

6. Where stripping takes place with both 80/100 bitumen and Road Tar Grade 3, higher viscosity binders such as 60/70 bitumen or Road Tar Grade 4 may be used with advantage depending on the time and type of construction.

TABLE 7

Evaluation of the various Aggregates based on Physical Tests and Adhesion Tests

Order	Specific gravity	Absorption	Crushing value	Per cent wear	Adhesion
1	Traps	Charnockites	Traps	Traps	Traps
2	Charnockites	Granites	Charnockites	Charnockites	Charnockites
3	Limestones	Quartzites	Sandstones	Limestones	Limestones
4	Sandstones	Sandstones	Limestones	Sandstones	Sandstones
5	Granites	Limestones	Quartzites	Granites	Quartzites
6	Quartzites	Traps	Granites	Quartzites	Granites

7. (a) Deccan traps, dolerites, charnockites, uncrushed river-shingles, and lime stones are found to have quite good adhesion with both bitumen and tar.

(b) Sandstones also show good adhesion, except the very coarse grained ones.

(c) All medium to fine grained quartzites and granites show good adhesion, while, the adhesion is poor when they are coarse grained.

(d) The presence of mafic minerals to a certain extent in a rock contributes much to the adhesion between it and the binder.

In general, coarse grained rocks, poor in mafic mineral content with coarsely crystalline surface texture show poor adhesion with bituminous binders.

8. To a certain extent, it is possible to forecast the adhesion characteristics of a roadstone based on the petrological data. But, actual laboratory tests should also be conducted with the materials to evaluate their suitability.

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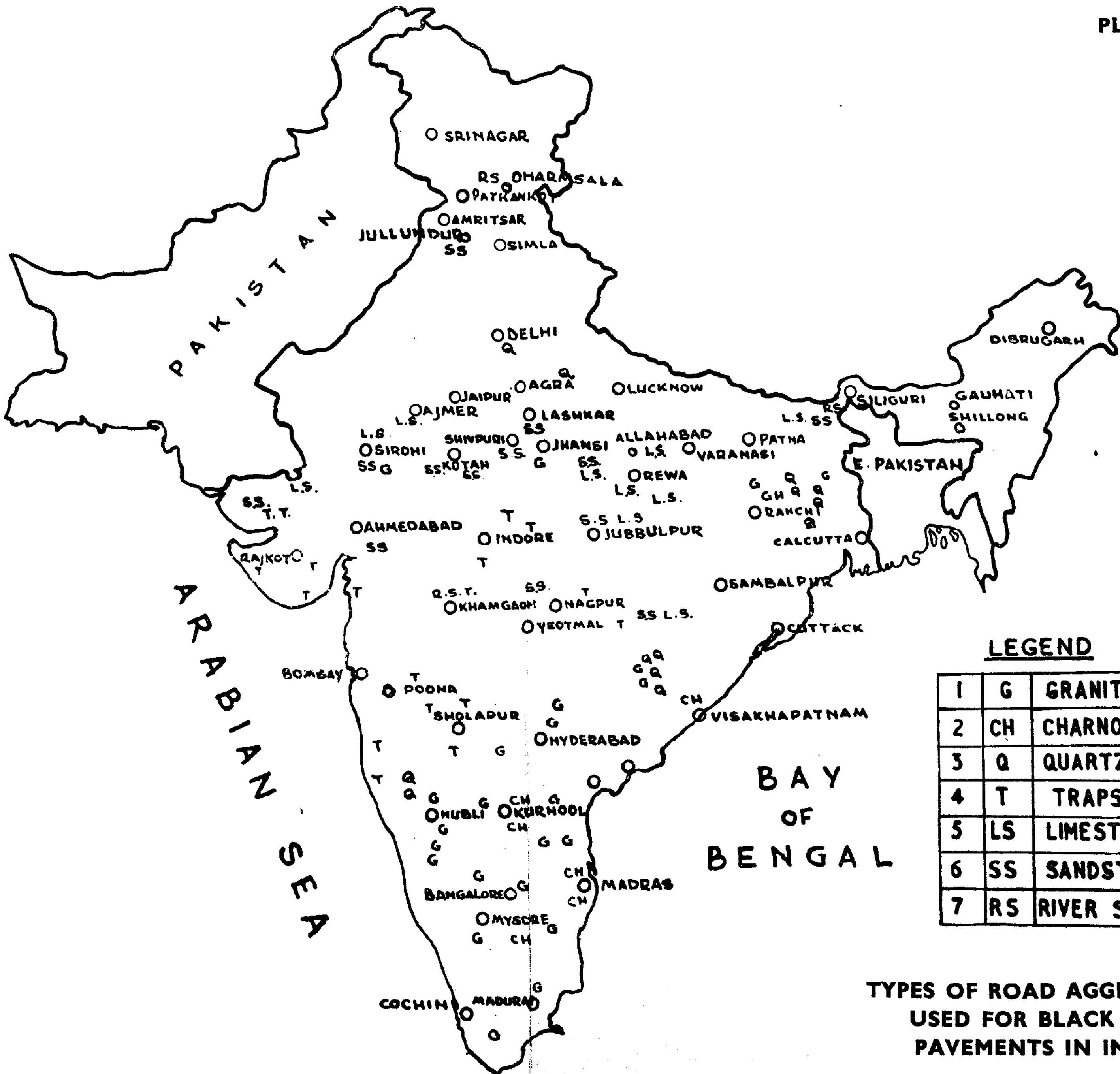
PLATE I



LEGEND

1	G	GRANITES
2	CH	CHARNOCKITES
3	Q	QUARTZITES
4	T	TRAPS
5	LS	LIMESTONES
6	SS	SANDSTONES
7	RS	RIVER SHINGLES

TYPES OF ROAD AGGREGATES USED FOR BLACK TOP PAVEMENTS IN INDIA

"CONSTRUCTION OF ALL-WEATHER SOIL STABILIZED PATRIES IN *USAR* AREAS: PART I—A COMPARATIVE STUDY OF THE EFFECT OF SODIUM SULPHATE AND SODIUM CARBONATE ON SOIL MASS"

By

MANOHAR LAL* & VINOD KUMAR RAIZADA*

1. INTRODUCTION

1.1. Salts play a very important role in the earth roads. Some salts like sodium chloride and calcium chloride when present in small quantities in the soil improve the general service value of the soil roads [1,2], on the other hand, some other salts like sodium sulphate or sodium carbonate when present in the soil adversely affect the soil mass under varying atmospheric conditions [3,4]. The *Usar* soil contains the above mentioned harmful salts and, therefore, patries or berms passing through these areas cannot be maintained in good condition. In Uttar Pradesh, *Usar* soils occur predominantly in several districts like Rae Bareli, Etawah, Mainpuri, Etah, Aligarh, Bulandshahr, Kanpur and Unnao where under average conditions of rainfall, temperature and humidity, the earth roads or patries become fluffy, where excessive detrimental salts are present.

The object of this investigation is to compare the detrimental effects of sodium sulphate and sodium carbonate when present in soil mass and to fix up limits upto which their presence in soil may not have adverse effects.

2. SOILS USED

2.1. For this study, four soils commonly met with in Uttar Pradesh were collected. Two more soils were adjusted as per Mehra's [5] specifications for base and wearing courses. The general physical and chemical properties of all the six soils were determined by the standard characterization tests, the results of which are given in Table 1.

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*P.W.D. Research Institute, Lucknow.

TABLE 1

Showing physical and chemical characteristics of soils

Sl. No.	Soil property	Test soil No. 1	Test soil No. 2	Test soil No. 3	Test soil No. 4	Test soil No. 5	Test soil No. 6
1.	Textural classification	Sandy loam	Sandy loam	Silty loam	Clay loam	Loam	Sandy clay loam
2.	P.R.A. Group classification	A4	A4	A4	A6	A4	A4
3.	Sand (0.05 mm.—2 mm.) per cent	61.0	55.6	24.8	35.1	49.5	65.32
4.	Silt per cent (0.005 mm.—0.05 mm.)	34.0	36.0	61.9	35.1	31.6	7.92
5.	Clay per cent (less than 0.005 mm.)	5.0	8.4	13.3	29.8	18.9	27.76
6.	Material retained on 200 mesh per cent	37.1	28.9	7.4	15.1	34.4	62.0
7.	Liquid limit	22.9	24.0	29.0	30.0	28.2	25.0
8.	Plasticity index	3.7	4.6	7.8	10.9	10.1	6.4
9.	Optimum moisture per cent	14.0	14.6	17.3	16.25	15.5	17.0
10.	Max. dry density lb/Cu.ft.	115.0	113.6	103.9	111.0	108.4	112.5
11.	C.M.E. per cent	8.2	9.02	9.24	11.14	8.86	11.22
12.	Shrinkage limit	14.88	19.26	22.35	10.97	13.33	14.83
13.	Speific Gravity	2.55	2.63	2.61	2.72	2.64	2.60
14.	*p*H	8.0	8.15	7.9	7.7	8.1	7.9
15.	Organic matter per cent	0.20	0.28	0.19	0.26	0.30	0.39
16.	Total water soluble sulphate and carbonate per cent	Nil	Nil	Nil	Nil	Nil	Nil
17.	Exchangeable Na & K, m.e. per 100 gms. of oven dry soil	0.50	0.95	1.50	1.25	1.01	1.1
18.	Exchangeable Ca, m.e. per 100 gms of oven dry soil	2.5	3.0	2.10	9.6	12.0	11.0

3. COMPARATIVE STUDY OF THE EXTENT OF DAMAGE ON COMPACTED SOIL MASS CONTAINING VARYING PERCENTAGES OF SODIUM SULPHATE AND SODIUM CARBONATE

3.1. Two sets of blocks of all the six soils were made at maximum compaction and optimum moisture with different percentages (varying from 0 to 5 per cent) of anhydrous sodium sulphate and anhydrous sodium carbonate separately added on dry weight of soil. These blocks were made in a split cylindrical mould which had a known internal volume 3 in. long and 2 in. in diameter. Samples containing a predetermined weight of the dry soil mixed with different percentages of salts were compacted at optimum moisture by placing the soil in the mould between the top and bottom plungers which were then pressed to the same weight in the soil compaction machine. One set of these blocks was subjected to twenty-four cycles of drying and weathering in humid atmosphere, (each cycle consisting of twenty-four hours drying in oven at 70°C and twenty-four hours weathering at a temperature, of 23°C—24°C and percentage humidity 90—95 per cent). The other set was subjected to twenty-four cycles of drying and weathering in a refrigerator (each cycle consisting of twenty-four hours drying in oven at 70°C and twenty-four hours keeping in refrigerator at a temperature of 6—8°C and humidity 85—95 per cent). Further, one set of blocks of test soil no. 5 containing different percentages of anhydrous sodium sulphate and anhydrous sodium carbonate varying from 0 per cent to 5 per cent was kept in a room subjected to changes of weather in Lucknow from 30-8-1958 to 1-4-1959. The temperature inside the room in this period varied from 11.5°C to 28.8°C and humidity varied from 60 to 94 per cent.

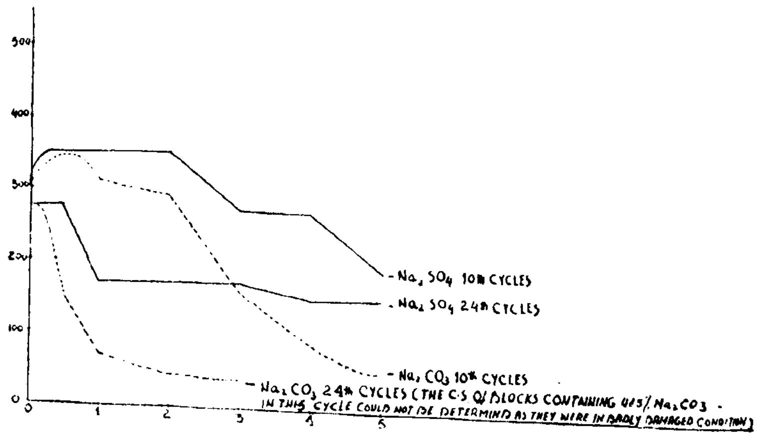
3.2. From visual examination of these sets of blocks placed under suitable condition for hydration and dehydration, it was observed that in the case of blocks containing sodium carbonate, 0.25 per cent of the salt proved harmless, 0.5 per cent showed no adverse effect except loosening of some particles in case of silty soil, but 0.75 per cent of salt caused crumbling from the surface. Blocks containing 1 per cent and 2 per cent salt showed enough damage and crumbling. Blocks having 3 per cent, 4 per cent and 5 per cent salt crumbled to fine powder at the 24th cycle.

3.3. In the case of blocks containing sodium sulphate, 0.25 per cent and 0.5 per cent of the salt proved harmless, 0.75 per cent showed no adverse effect except slight attack in case of silty soil, blocks having 1, 2 and 3 per cent salt showed loosening of soil with slight crumbling, blocks having 4 and 5 per cent salt showed swelling, cracking, and crumbling.

3.4. It was also observed that samples with base and wearing course specifications and clay loam (test soil No. 4) showed better resistance to damage by sodium sulphate and sodium carbonate than the other soils. Test soil No. 3 (silty loam) was the soil which was affected very rapidly and showed the worst damage. Test soils no. 1 and 2 showed damage intermittent in between the best and worst soils.

3.5. With a view to obtain further idea of the damaging action of salts, blocks containing varying percentages of anhydrous sodium sulphate and anhydrous sodium carbonate added on dry weight of soil, were subjected to different cycles of drying and weathering as per details given in para 3.1. One set of blocks containing different percentages of either sodium sulphate or sodium carbonate varying from 0 to 5 per cent was tested for compressive strength at different cycles.

The results shown in Fig. 1 for 10th and 24th cycles indicate that for same percentage, the compressive strength of the blocks containing sodium carbonate is considerably reduced as compared to the blocks containing sodium sulphate showing thereby that sodium carbonate has more damaging effect than sodium sulphate.



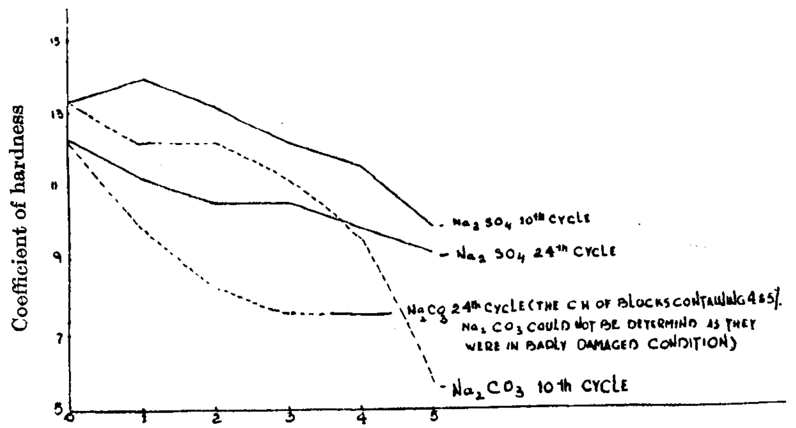
PER CENT SALT ADDED (TO DRY WEIGHT OF SOIL)

Fig. 1. Graph showing compressive strength of blocks containing Na_2SO_4 & Na_2CO_3 as affected by increasing cycles of drying & keeping in humid atmosphere

3.6. The fact that sodium carbonate is more harmful than sodium sulphate while present in soil mass has been proved by the coefficient of hardness test performed in Dorry's Abrasion Machine [6]. A load of two hundred gms was used to press each block of size 3 in. × 2 in. and sand passing 30 A.S.T.M. mesh sieve

and retained on 40 A.S.T.M. mesh sieve was used. The disc was revolved through hundred revolutions instead of one thousand at 28 r.p.m.

Compacted soil blocks of test soil no. 6 (base course soil) containing varying percentages of either sodium sulphate or sodium carbonate were subjected to twenty-four cycles of drying and weathering as per details given in para 3.1. The coefficient of hardness of these blocks was determined at various cycles of weathering and drying. The results are given in Fig. 2 for 10th and 24th cycles which indicate that blocks containing sodium carbonate show more



PER CENT SALT ADDED TO DRY WEIGHT OF SOIL

Fig. 2. Curves showing coefficient of hardness of blocks containing varying percentages of Na_2SO_4 & Na_2CO_3 as affected by increasing cycles of drying & keeping in humid atmosphere

decrease in coefficient of hardness than blocks having same percentage of sodium sulphate, indicating that sodium carbonate is more destructive than sodium sulphate.

4. A STUDY OF CAUSES RESPONSIBLE FOR MORE DAMAGE BY SODIUM CARBONATE THAN BY SODIUM SULPHATE

4.1. Volume change

In order to study the volume change in soil mass and salts alone when placed in conditions suitable for hydration, the apparatus used is shown in Fig. 3.

Different percentages of anhydrous sodium sulphate and anhydrous sodium carbonate were added to fifty gms of dry soil (test

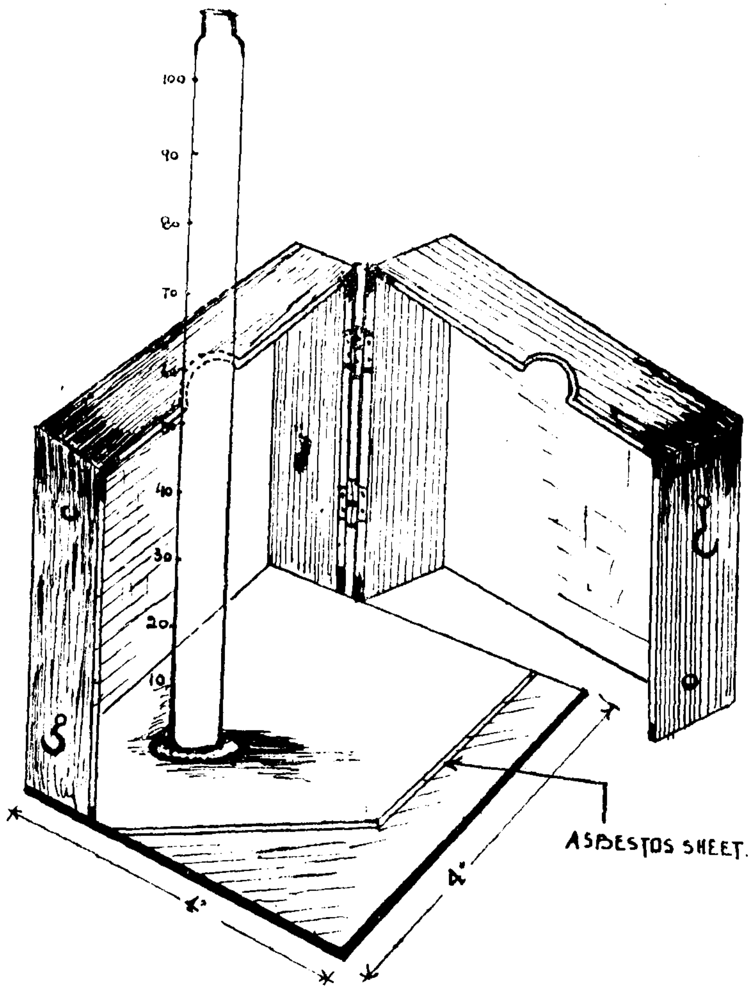


Fig. 3. Apparatus used for determining volume

soil no. 6) in petri dishes separately. They were thoroughly mixed and the volume recorded in each case by filling it in the graduated cylinder, Fig. 3. The cylinder was lifted to the top and then allowed to fall to the base of the box, the height of fall being ten cms. Ten such strokes were given. The volume in each case was then recorded in cubic centimeters. The soil sample in each case was then transferred to the petri dish and kept in the room at a constant temperature 23°C and humidity 90 per cent, for twenty-

four hours. After twenty-four hours, its volume was again recorded and percentage gain in volume was calculated. The soil sample in each case was then heated at 100°C to constant weight and the volume of salt mixed soil was again determined. The results are

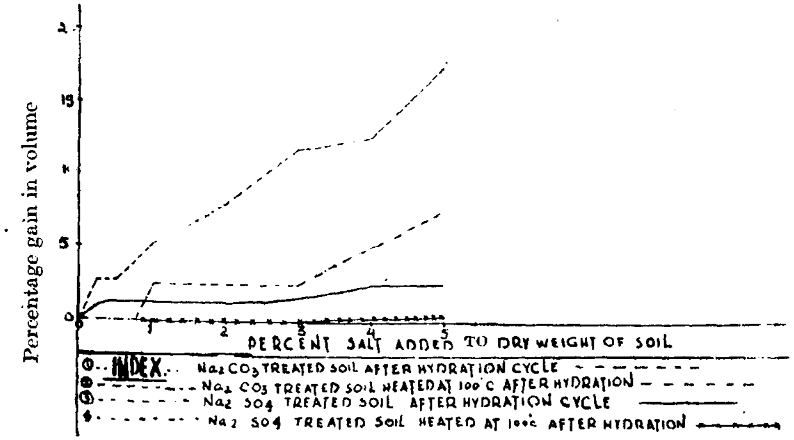


Fig. 4. Graph showing volume of soil as affected by the addition of increasing percentages of Na_2SO_4 & Na_2CO_3

shown in Fig. 4. Also, for the study of volume change in case of salts alone, equal amount of each of anhydrous sodium sulphate and sodium carbonate was taken in a petri dish and their volumes recorded. They were then subjected to the same temperature humidity and drying conditions as the mixed soil samples and the volumes were determined again. The results are given in Table 2.

TABLE 2

Showing volume change in salts

Sl. No.	Name of salt	Per cent gain in volume in 24 hours at 23°C and 90 per cent humidity	Per cent increase in volume from initial volume after heating at 100°C to constant weight
1.	Na_2SO_4	5.7	0.05
2.	Na_2CO_3	14.1	1.4

From the results in Fig. 4 and Table 2, it is clear that sodium carbonate shows more **percentage increase in volume on hydration**

when alone as well as when added to soil mass than the same percentage of sodium sulphate. It is evident from Fig. 4 that soil having 5 per cent sodium carbonate shows 17.5 per cent increase in volume while the soil having the same percentage of sodium sulphate shows only an increase of 2.6 per cent. Thus as sodium carbonate shows more increase in volume than the sodium sulphate, it is likely that it will cause more damage. When the soil samples treated with salts and salt samples were heated to 100°C, after hydration it was found that in case of sodium sulphate, the increased volume was almost reduced to its normal volume while in case of soil treated with sodium carbonate, it did not reach its initial volume, Fig. 4. This may be due to auto-disintegration and this aspect is discussed separately in para 4.4.

4.2. Weight Change

In order to study the change in weight, different percentages of anhydrous sodium sulphate and anhydrous sodium carbonate were added to 50 gms of dry weight of test soil no. 6 in petri dishes separately. The salts were thoroughly mixed with the soil and their weights recorded. Later they were kept in a room at a constant temperature of 23°C and humidity 90 per cent. Their weights were then recorded and the percentage gain in weight was calculated. After hydration, the soil samples treated with salt in each case were then heated at 100°C to a constant weight and percentage gain in weight from initial weight was calculated. The results are given in Fig. 5. For the study of percentage increase in

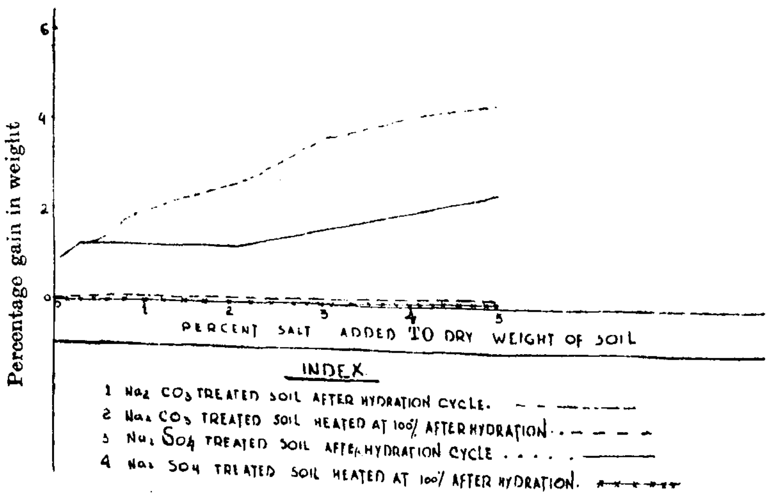


Fig. 5. Graph showing weight of soil as affected by the addition of increasing percentages of Na_2SO_4 & Na_2CO_3

weight of the salts also, the same procedure was allowed and percentage increase of weight after hydration as well as after heating to a constant weight at 100°C was noted. The results given in Table 3 indicate that sodium carbonate shows more increase in weight than sodium sulphate. These results are in agreement with the results reported by L. R. Chadda and Hem Raj[7]. Consequently, as sodium carbonate shows more percentage increase in weight than sodium sulphate in conditions suitable for hydration, increased absorbed moisture is likely to cause more auto-disintegration and increase in volume of soil mass, resulting in more damage.

4.3. Auto-disintegration

Puri [8] has suggested that sodium soils in contact with water undergo auto-disintegration which increases with increase of pH values. When sodium carbonate is placed under conditions suitable for hydration for twenty-four hours, it takes 18.01 per cent moisture and under similar conditions sodium sulphate absorbs 0.06 per cent moisture (Table 3). This moisture absorbed by sodium carbonate may be sufficient to effect auto-disintegration in soil heated with sodium carbonate. As auto-disintegration

TABLE 3

Showing weight change in salts

Sl. No.	Name of salt	Per cent gain in weight in 24 hours at 23°C and 90 per cent humidity	Per cent gain in weight from initial wt. after heating at 100°C to constant weight
1.	Na_2SO_4	0.06	0.0
2.	Na_2CO_3	18.01	0.50

is also expected to increase with pH values. The pH values of soil treated with varying percentages of sodium sulphate and sodium carbonate were determined by the method adopted by C.S. & I.R. division of soils [9] after subjecting the samples to various cycles of drying and keeping in constant temperature room in accordance with details in para 3.1. The results are given in Table 4 which show that increase in pH value in the case of soil treated with sodium carbonate is greater as compared to soil treated with sodium sulphate and this difference is maintained in different cycles. It may, therefore, be concluded that under similar conditions of hydration, sodium carbonate may cause more disintegration of soil mass than sodium sulphate and thus increase the volume of soil mass. This auto-disintegration reduces soil to finer particles and thus increases its volume. This increased volume on dehydration does not reach its original volume but shows a permanent increase in volume showing that soil has been dispersed to finer particles, whereas in case of sodium sulphate approximately the same volume is obtained on dehydration, Fig. 4.

TABLE 4

Showing pH values of soil treated with Na_2SO_4 and Na_2CO_3

Sl. No.	Per cent salt added to dry weight of soil		pH		
			No cycle	10th cycle	24th cycle
1.	Blank (no salts)		7.9	7.9	7.9
2.	Sodium sulphate	– 0.25	7.5	7.5	7.5
3.	-do-	– 0.5	7.5	7.5	7.5
4.	-do-	– 0.75	7.5	7.5	7.5
5.	-do-	– 1.0	7.5	7.8	7.8
6.	-do-	– 2.0	7.7	8.1	8.1
7.	-do-	– 3.0	8.0	8.2	8.25
8.	-do-	– 4.0	8.0	8.25	8.3
9.	-do-	– 5.0	8.05	8.3	8.3
10.	Sodium carbonate	– 0.25	8.45	8.5	9.0
11.	-do-	– 0.5	8.8	9.0	9.2
12.	-do-	– 0.75	9.1	9.2	9.4
13.	-do-	– 1.0	9.3	9.3	9.4
14.	-do-	– 2.0	9.35	9.4	9.4
15.	-do-	– 3.0	9.4	9.4	9.45
16.	-do-	– 4.0	9.4	9.4	9.5
17.	-do-	– 5.0	9.4	9.4	9.5

The possibility of the increase of volume due to the existence of $Na_2CO_3.H_2O$ at 100°C has also been studied. It is known that last one molecule of sodium carbonate is not given off at a temperature of 100°C. Therefore, its retention at 100°C may also increase the volume of the soil mass containing sodium carbonate. But this salt under similar conditions of hydration and then heating at 100°C to constant weight showed a volume increase of 1.4 per cent (Results Table 2). So, consequently 5 per cent of sodium carbonate when present in the soil will show volume increase by 0.07 per cent due to retention of one molecule of water, when the increase in volume has been found to be actually 7.3 per cent, Fig. 3. Similarly, excessive increase of volume in soil mass as shown in Fig. 3 is due to auto-disintegration. This, therefore, conclusively proves that the auto-disintegration is responsible for increase of volume in soil containing sodium carbonate and consequently causing more damage.

5. CONCLUSIONS

5.1. In compacted soil, 0.5 per cent sodium sulphate and 0.25 per cent sodium carbonate do not show any damage.

5.2. For equal percentages, sodium carbonate is comparatively much more destructive to soil mass than sodium sulphate.

5.3. Soil with base and wearing course specifications and clay loam show better resistance to damage by sodium sulphate and sodium carbonate than the other soils. Silty loam soils are attacked rapidly and show worst damage.

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