International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878, Volume-8 Issue-5, January 2020

Characterization of Classified Indian Reclaimed Asphalt Pavement (RAP): In-Situ and Lab Density, Bitumen Content and Gradation Characteristics.

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Abstract: ***Reclaimed asphalt pavement (RAP) is the term given to removed and/or reprocessed pavement materials containing asphalt and aggregates. These materials are generated when asphalt pavements are removed for reconstruction, resurfacing, or to obtain access to buried utilities. When properly crushed and screened, RAP consists of high-quality, well-graded aggregates coated by asphalt cement. Process of utilization of reclaimed asphalt pavement (RAP) is called recycling of asphalt pavement. RAP material is generated when old, damaged pavement materials are milled and crushed for addition as a component to new mixtures placed in the pavement structure. Historically, old pavement material was removed and disposed of in landfills. As land filling these materials has become less practical and more expensive and the availability of quality virgin materials declines, the addition of RAP to pavement mixtures has become more and more prevalent. Recycling of pavement material can be done as an in-place process or a central plant process. The in-place process combines the reclamation, mixing, lay down, and compaction procedures into a single paving train in the field. In-place recycled materials are typically used for base or binder courses and are typically overlaid with a surface course. The central plant process involves stockpiling RAP at the asphalt plant, which is then mixed with virgin materials at the plant and trucked to the construction site for lay down and compaction. Use of RAP in road construction will reduce depletion of virgin aggregates resources and also overcome to disposal problem of bituminous wastes. It is required to access properties of RAP aggregate and recovered bitumen before using in actual road pavements. RAP samples collected and a series of tests are performed for characterization and performance evaluation of selected RAP samples of different groups. In this study characterization of RAP limited to in-situ and lab density along with bitumen content and gradation of RAP classified in different groups. Results of this study will be beneficial in job mix formula (JMF) design with varying percentage of RAP to be use in bituminous layer in flexible pavements.***

This study is a step towards sustainable developments with green road construction i.e. construction of flexible pavement with environmental protection and conservation of natural resources.

Keywords: Rap, Reclaimed, Recycling, Aggregates, Bitumen, Bituminous mix, Asphalt, Characterization, Performance, Density, Bitumen content, gradation.

I. NTRODUCTION

India had the one of the largest road networks in the world, spanning over a total of 5.6 million kms. Over 64.5 per cent of all goods in the country are transported through roads, while, 90 per cent of the total passenger traffic uses road network to commute. During FY18-19, Government of India allocated Rs 71,000 crore (US$ 10.97 billion) for development of national highways across the country. As on September 2017, 312 projects were recommended for development by the Public Private Partnership Appraisal Committee (PPPAC). Investment of US$ 31 billion is expected in PPP by 2020 for national highways .The Government of India plans to increase the length of National Highways up to 200,000 kms. As of November 2017, national highways of 4,944 kms in length were constructed, against a target of 15,000 kms for FY 2017-18, under various road transport and highway projects [1] Road network in India is sub-divided into three categories i.e. National Highways (NH), State Highways (SH) and District and Rural Roads . As in September, 2017, total length of National Highways (NHs) /Express Ways in India was 1, 15,530 km which accounted for 2.06 per cent of the total road length. On the other hand, the length of State Highways was 1,76,166 km as on 2015-16. Length of District and Rural Roads is 5,326,166 kms which is 95 percent of total road length in India. The Government received proposals for declaration of more than 64000 km of State roads as National Highways (NHs) from various State Governments, against which the Ministry of Road and Transportation has declared about 10000 km of Roads/routes as new National Highways[2]. After all Annual Report 2018-19 of Government of India, Ministry of Road Transport& Highway, New Delhi reports that India has about 58.98 lakh km of road network, which is the second largest in the world after United state. This Comprises National Highways, Expressways, State Highways, Major District Roads, Other District Roads and Village Roads [3].

Manuscript published on January 30, 2020.
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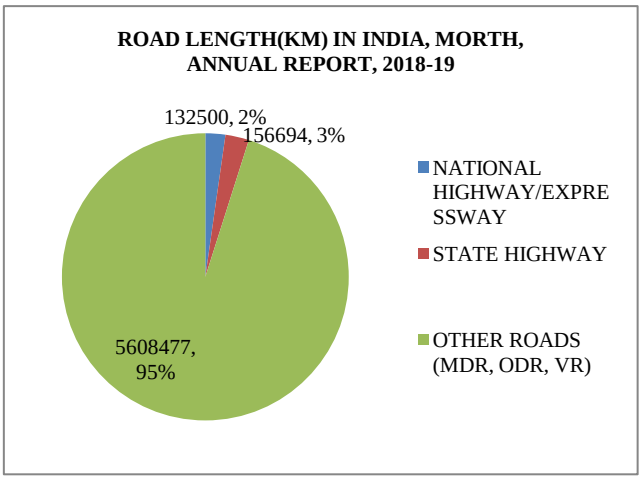


Thus India has a large road network and it required a considerable amount of financial and natural resources in construction, maintenance and rehabilitation of road assets. As overall budgetary funds are always limited, innovation is required in order to do more preventive maintenance, rehabilitation, reconstruction of roads at a lesser cost. Pavement recycling is one such effective and well established proven technology for increasing the effectiveness of being able to do more at lesser cost. It is a logical and practical solution to conserve our diminishing supply of construction materials and to help reduce the ever increasing cost of preserving of existing pavement network. Pavement recycling is not a new concept and recycling of bituminous pavements is a standard practice in many countries of the world since last 35 years. The various ecological and economic advantages which contributed to rapid enhancement of recycling processes throughout the world are:

- Conservation of aggregates and binder.
- Preservation of the environment and conservation of natural resources.
- Preservation of existing pavement geometrics and clearances.
- Conservation of energy and labour.
- Less user delay during construction.
- Reduction in reflection cracking.
- Substantial saving in terms of cost. [4]

Bituminous pavement recycling technology is not yet a popular in India. However, in advanced countries, bituminous material is the most recycled material in the construction industry. For example, in USA, 33 million tons of RAP is used per year for recycling purpose which is around 80% of the total amount of RAP collected from old bituminous pavements. The amount of RAP used for recycling per year is about 0.84 million tons in Sweden, 7.3 million tons in Germany, 0.53 million tons in Denmark and around 0.12 million tons in Netherlands. In the year 1995, 20 million tons of recycled hot mix was produced in Japan, which constituted 30% of the total hot mix production. [5].

In India it is highly required to recommend recycling of bituminous pavement in rehabilitation of existing roads and in construction of new roads [6]. But as on today sufficient guidelines and standards are not available in India. So it becomes first priority to develop guidelines and standards pertaining use of recycled or reclaimed asphalt pavement (RAP). In this way first step will be characterization of classified reclaimed asphalt pavement (RAP) by investigating characteristics or properties of RAP aggregates and recovered bitumen. This study deals with finding out characteristics or properties of RAP aggregates by conducting laboratory experiments on aggregates obtained from different categories of reclaimed asphalt pavements (RAP) classified on the basis of origin and sources of RAP. On the basis of origin and sources RAP are classified in four categories i.e. PS, BS, DS & DB Groups [7] as given in Table No.1.Availability of RAP sample at site is shown by figure 01.

Figure 01: Availability of Bituminous Waste as Reclaimed Asphalt Pavement (RAP)

Table No.01: Categorization of RAP in Different Groups [7]

Sl. No.	Recycled Layers	Group of Sample	Description
1.	PC+SEAL	PS	Initially Open Graded Premix Carpet (OGPC) and Seal Coat exist at the road from where sample is collected.
2.	BM+SDBC	BS	Initially Semi Dense Bituminous Concrete Over layer of Bituminous Macadam exist at the road from where sample is collected.
3.	DBM+SDBC	DS	Initially Semi Dense Bituminous Concrete Over layer of Dense Bituminous Macadam exist at the road from where sample is collected.
4.	DBM+BC	DB	Initially Bituminous Concrete Over layer of Dense Bituminous Macadam exist at the road from where sample is collected.

II. MATERIAL

The RAP is a deteriorated bituminous mix that contains aged bitumen and aggregates. Hence, its performance is poorer when compared to the fresh mix. The purpose of the bituminous recycling is to regain the properties of the RAP; such that is tends to perform as good as fresh mix. Thus, the process of bituminous recycling involves mixing of the RAP after Crushing, Screening and Stock Pilling. Use of RAP materials in road constructions will require characterized RAP, bitumen rejuvenators and virgin aggregates etc. Generally reclaimed asphalt pavement (RAP) is available as mixture of material used in binder/bituminous base course and wearing/surface course. Hence they cannot separate from removed bituminous material. Thus sampling of RAP is done for further study is given in table no 2. Minimum four road sites are selected for sampling of each group of reclaimed asphalt pavement. At least four chainages identified on each road and minimum four samples collected at each chainage. This indicates that total number of samples in each RAP group will be 64. As per existing guidelines and standards flexible pavements includes different bituminous layers which recycled depending upon traffic count as CVPD of a particular road. If CVPD is up to 2.0 msa OGPC (open graded premix carpet) with seal coat used; 2.0- 5.0 msa SDBC over BM or DBM used; If CVPD if more than 5.0 msa BC over DBM layer used. Different groups of RAP samples are collected from different roads of Lucknow and Barabanki district of Uttar Pradesh in India. All the samples are collected 15-30 year period of flexible pavement. Complete details of collected samples are given in Table No. 2 and collected cores and crushed sample are shown in figure no. 02

III. METHODOLOGY:

Experimental work done with different set of RAP samples and results can be used to characterize the RAP materials. First of all RAP collected from different areas and different roads for this study. Samples were oven dried and crushed so that lumps were break to a level so that each and every bitumen coated coarse aggregates separated to each other. Bitumen from RAP sample washed out by using trichloroethylene or benzene solution and extracting with bitumen extractor. These samples were oven dried again and sieved on IS designated sieves and results were summaries for further study of performance of reclaimed asphalt pavement (RAP) aggregates in different layers of pavements. Methodology developed for characterization of Indian reclaimed asphalt pavement will include steps listed below [7]:-

Step1: Identification of roads for collection of reclaimed asphalt pavement (RAP).
Step2: Identification of roads road stretches where bituminous layer is intact.
Step3: Finding in-situ density by sand replacement, non nuclear and nuclear density gauges.
Step4: Collection of core and disturbed samples from identified road sites.
Step5: Cores are tested to find out lab density.
Step6: Drying samples in oven for 24 hours at 100^0 C.
Step7: Crushing of oven dried collected samples.
Step8: Washing of crushed samples with trichloroethylene or benzene solution.
Step9: Another part of sample put in ignition furnace.
Step10: Recording bitumen content found in step 8& 9.
Step11: Sieve analysis of washed, extracted and oven dried samples.
Step12: Tabulation of result of sieve analysis and graphical presentation of gradation pattern.
Step 13: Averaging the result for predicting gradation pattern.
Step 14: Presenting All results of density, bitumen content and gradation for each group separately.
Step 15: Summarizing findings of study and statistical analysis of data.

Table No.2: Sampling of RAP of Different Groups [7]

Sl. No.	Group of Sample	Coding of different Samples	Chainage	Name of Roads	Location	Category of Roads
1.	PS	PS1 PS1' PS1'' PS1'''	0.400 Km 1.500 Km 2.600 Km 3.700 Km	Para Link Road	Lucknow, Uttar Pradesh, India	Village Roads (VR)
		PS2 PS2' PS2'' PS'''	0.800 Km 1.600 Km 2.500 Km 3.800 Km	Amity college to Khargapur Link Road	Lucknow, Uttar Pradesh, India	Village Roads (VR)
		PS3 PS3' PS3'' PS3'''	3.200 Km 4.500 Km 5.400 Km 6.200 Km	Lalpur Link Road	Lucknow, Uttar Pradesh, India	Village Roads (VR)
		PS4 PS4' PS4'' PS4'''	2.300 Km 3.500 Km 4.600 Km 5.800 Km	Nigoha Bazar to Meerak Nagar Link Road	Lucknow, Uttar Pradesh, India	Village Roads (VR)
2.	BS	BS1 BS1' BS1'' BS1'''	36.400 Km 37.500 Km 38.600 Km 39.700 Km	Haidergargh-Subeha-Shukul Bazar Road (ODR)	Barabanki, Uttar Pradesh, India	Other District Road (ODR)

		BS2 BS2' BS2'' BS2'''	10.100 Km 11.500 Km 12.300 Km 13.600 Km	Bhanmau-Zaidpur-Safdarganj-Badosarai Road (ODR)	Barabanki, Uttar Pradesh, India	Other District Road (ODR)
		BS3 BS3' BS3'' BS3'''	23.400 Km 24.600 Km 25.600 Km 26.800 Km	Barabanki-Deviganj-Subeha Road (ODR)	Barabanki, Uttar Pradesh, India	Other District Road (ODR)
		BS4 BS4' BS4'' BS4'''	09.400 Km 10.200 Km 11.600 Km 12.400 Km	Mohammadpur-Siddhaur-Kaiserganj Road (ODR)	Barabanki, Uttar Pradesh, India	Other District Road (ODR)
3.	DS	DS1 DS1' DS1'' DS1'''	130.200Km 131.400Km 132.600Km 133.800Km	Barabanki-Haidergargh-Bachhrawan Road (SH-13)	Barabanki, Uttar Pradesh, India	State Highway (SH)
		DS2 DS2' DS2'' DS2'''	10.400 Km 11.200 Km 12.400 Km 13.200 Km	Haidergargh-Ramsnehighat Road (MDR-3)	Barabanki, Uttar Pradesh, India	Major District Road (MDR)
		DS3 DS3' DS3'' DS3'''	16.400 Km 17.500 Km 18.600 Km 19.700 Km	Intauja-Mahona-Kumhrawan-Kursi-Deva-Chinhat Road (MDR-88)	Barabanki, Uttar Pradesh, India	Major District Road (MDR)
		DS4 DS4' DS4'' DS4'''	1.400 Km 2.500 Km 3.600 Km 4.700 Km	Haidergargh-Maharajganj Road (SH-13A)	Barabanki, Uttar Pradesh, India	State Highway (SH)
4.	DB	DB1 DB1' DB1'' DB1'''	260.400 Km 261.500 Km 262.600 Km 263.700 Km	Palia-Shahjanpur-Hardoi Road (SH-25)	Lucknow, Uttar Pradesh, India	State Highway (SH)
		DB2 DB2' DB2'' DB2'''	59.400 Km 60.400 Km 61.600 Km 62.300 Km	Lucknow-Sultnpur Road (NH-56)	Barabanki, Uttar Pradesh, India	National Highway (NH)
		DB3 DB3' DB3'' DB3'''	22.400 Km 23.500 Km 24.600 Km 25.700 Km	Lucknow-Faizabad-Gorakhpur-Mokama Road (NH28)	Barabanki, Uttar Pradesh, India	National Highway (NH) City Portion.
		DB4 DB4' DB4'' DB4'''	2.400 Km 3.500 Km 4.600 Km 5.700 Km	Barabanki-Bahraich-Nanpara-Rupaidiha road (NH-28 C)	Barabanki, Uttar Pradesh, India	National Highway (NH)

Figure 02: Sampling of Reclaimed Asphalt Pavement (RAP)

IV. EXPERIMENTAL PROGRAM :

Different tests on cores of RAP and crushed and oven dried RAP aggregate samples were done in four lots for each group of RAP. Each lot has at least sixteen samples of RAP collected at Identified road sites. Laboratory test are done on original RAP samples and RAP aggregates and findings are given in tables. Graphical and pictorial presentation along with statistical analysis of data executed. Three laboratory tests are conducted on Original RAP samples to study about properties of RAP:

i. Binder/Bitumen Content
ii. Density of Cores
iii. Moisture Content

Further Characterization of RAP aggregates can be done by conducting seven laboratory tests on RAP aggregates:

i. Gradation
ii. Shape Tests
iii. Aggregate Impact Value (AIV)
iv. Abrasion
v. Crushing
vi. Polished Stone Value
vii. Soundness

Further characterization of Reclaimed Asphalt Pavement (RAP) will require characterization of recovered bitumen. Characterization of recovered bitumen can be done by conducting nine laboratory tests on recovered bitumen of RAP of different class. Tests are listed below:

i. Penetration Test
ii. Ductility Test
iii. Softening Point Test
iv. Specific Gravity Test
v. Viscosity Test
vi. Flash and Fire Point Test
vii. Float Test
viii. Determination of Water Content
ix. Determination of loss on Heating

V. SCOPE OF STUDY:

Characterization of reclaimed asphalt pavement (RAP) is itself a broad area, but this paper is limited to study of existing properties of reclaimed asphalt pavement (RAP) i.e.:

i. In-Situ/Field Density of RAP
ii. Density of RAP Cores in Laboratory.
iii. Bitumen Content of RAP
iv. Gradation of RAP

In-Situ/Field Density of RAP: Existing density of RAP material only at intact portion of bituminous layer can be find out if and only if bituminous layer is intact at the road site selected for recycling of bituminous pavement cutting of core for laboratory study is also possible only in intact bituminous layer . Evaluation of field density of deteriorated pavements can be done in field generally by three methods:

i. Sand Replacement Method
ii. Non Nuclear Density Gauge/Electrical Density Gauge
iii. Nuclear Density Gauge

In this study at each and every locations three methods are used to find out field density of deteriorated pavements i.e. RAP. Setup and equipments of above methods to find out density is shown in Figure 03.

Density of RAP Cores in: Laboratory density is accurate assessment of density of RAP cores in ideal condition of laboratory. Laboratory density of cores assed by finding weight and volume of cores in laboratory and density is calculated.

Bitumen Content of RAP: Bitumen Content of RAP samples can be find out by two methods:

i. Extraction Method
ii. Ignition Method

In extraction method RAP sample washed and extracted by Bitumen Extractor using solvent like Benzene or trichloroethylene, and bitumen content calculated. In ignition method RAP sample ignited in automated electric asphalt furnace and automatically bitumen content is obtained on screen or in form of printed slip.

Gradation of RAP: RAP aggregate samples are finding out in laboratory by separating binder by extraction or ignition and dried in oven at 100^0C. Oven dried RAP samples sieved with set of IS designated sieve set and compared with standard gradation of BC and DBM.

Setup and equipments of above methods to find out bitumen content and gradation pattern is shown in Figure 04.

VI. FINDINGS:

Field density test on sources of RAP performed at different sites of deteriorated pavement. Each and every site tests will include all three methods i.e. sand replacement method, non-nuclear density gauge method and nuclear density gauge method. After density test Cores of RAP sample tested in laboratory to find out lab density of the cores. Extra RAP cores/samples are used to find out bitumen content by two methods i.e. bitumen extraction method and ignition method. After extraction or ignition aggregate samples are sieved to find out gradation characteristics and gradation pattern and patterns are compared with standard gradation of BC and DBM as per Indian Standards. Group wise results were summarized as below:-

A. "Group PS" RAP: These are RAP Samples collected from the deteriorated pavement sites where initially bituminous layer is OGPC and Seal Coat over a granular layer. In practice these types of RAP samples are available at Village Roads (VR) where initial CVPD after construction is up to 2.0 msa. Characteristics of this group are presented by table no.03& 04 and plot no.01.

Table No. 03: Density and bitumen content characteristics of "Group PS"

Sl. No.	Sample Code	Field Density			Lab Density	Bitumen Content	
		Sand Replacement	Non Nuclear Density Gauge	Nuclear Density Gauge		Extraction	Ignition
1.	PS1	1.60	1.58	1.58	1.58	2.69	2.66
2.	PS1'	1.61	1.58	1.57	1.57	2.7	2.66
3.	PS1''	1.60	1.58	1.57	1.57	2.69	2.66
4.	PS1'''	1.60	1.59	1.58	1.58	2.69	2.68
5.	PS2	1.61	1.61	1.60	1.60	2.7	2.70
6.	PS2'	1.61	1.61	1.60	1.60	2.71	2.70
7.	PS2''	1.60	1.59	1.60	1.58	2.7	2.70
8.	PS2'''	1.60	1.60	1.60	1.60	2.7	2.70
9.	PS3	1.61	1.60	1.60	1.60	2.7	2.69
10.	PS3'	1.62	1.62	1.62	1.61	2.71	2.71
11.	PS3''	1.58	1.57	1.59	1.60	2.7	2.70
12.	PS3'''	1.60	1.60	1.61	1.61	2.71	2.71
13.	PS4	1.58	1.49	1.50	1.48	2.72	2.55
14.	PS4'	1.59	1.58	1.59	1.58	2.71	2.56
15.	PS4''	1.60	1.59	1.59	1.58	2.69	2.59
16.	PS4'''	1.61	1.59	1.60	1.58	2.7	2.70

Table No.04: Gradation of "Group PS" RAP

IS sieve (mm)	Mid Point of Cumulative percentage by weight of total aggregate passing		
	RAP PS	BC	DBM
45	100	100	100
37.5	100	100	95
26.5	100	100	78
19	100	100	-
13.2	95	95	65
9.5	77	79	-
4.75	65	62	46
2.36	52	50	35
1.18	42	41	-
0.6	33	32	-
0.3	25	23	14
0.15	18	16	-
0.075	8	7	5
0.00	0	0	0

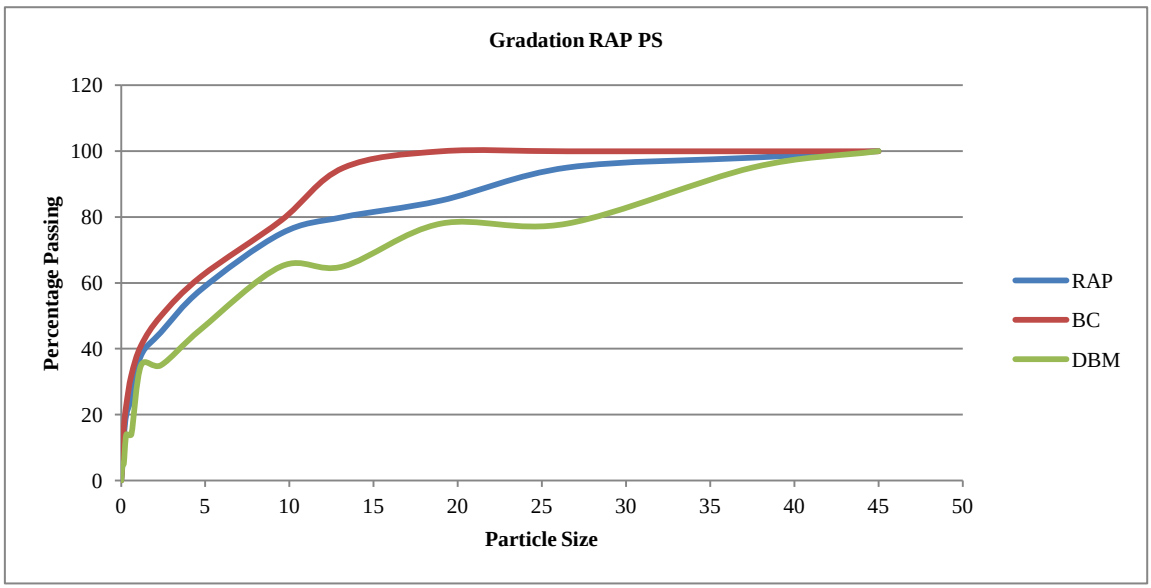


Figure 02: Sampling of Reclaimed Asphalt Pavement (RAP)

Figure 03:Sand Replacement Equipment, Nuclear Density Gauge (HUMBOLDT) and Non-nuclear Density Gauge (PAB1)

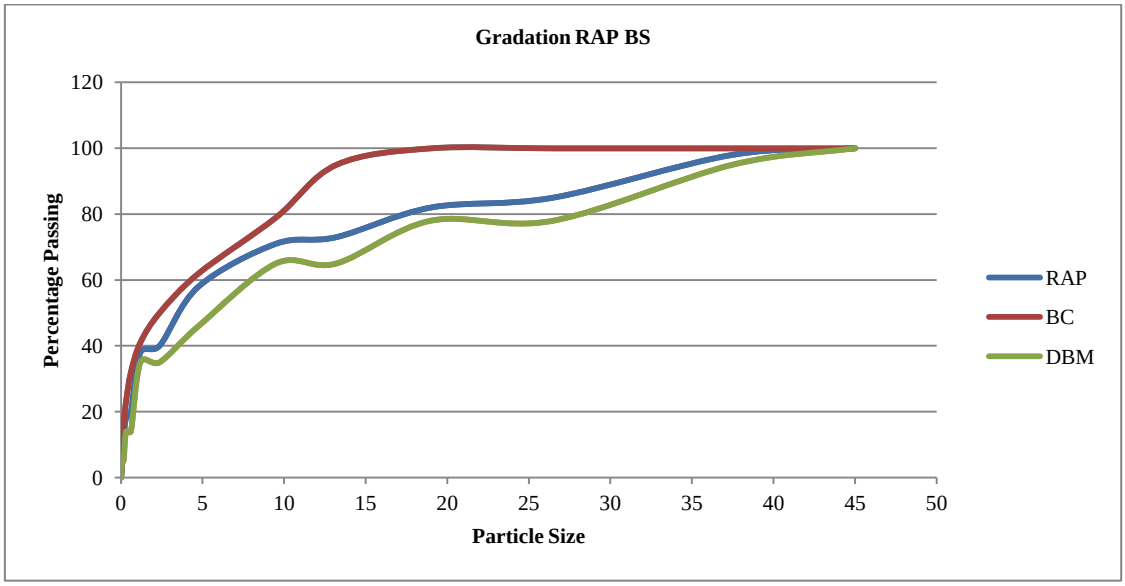
B. "Group BS" RAP: These are RAP samples collected from the deteriorated pavement sites where initially bituminous layer is Semi Dense Bituminous Concrete (SDBC) over layer of Bituminous Macadam supported by a granular base. In Practice these type of RAP samples are available at Other District Roads (ODR) and Major District Roads (MDR) where initial CVPD after construction is up to 2.0 to 5.0 msa. Characteristics of this group are presented by table no.05& 06 and plot no.02.

Table No. 05: Density and bitumen content characteristics of "Group BS"

Sl. No.	Sample Code	Field Density			Lab Density	Bitumen Content	
		Sand Replacement	Non Nuclear Density Gauge	Nuclear Density Gauge		Extraction	Ignition
1.	BS1	1.70	1.68	1.68	1.68	2.90	2.88
2.	BS1'	1.72	1.72	1.70	1.70	2.93	2.92
3.	BS1''	1.72	1.72	1.70	1.70	2.90	2.89
4.	BS1'''	1.80	1.80	1.80	1.78	3.10	3.00
5.	BS2	1.81	1.80	1.80	1.79	3.10	3.00
6.	BS2'	1.80	1.79	1.80	1.78	3.10	3.00
7.	BS2''	1.80	1.80	1.80	1.80	3.20	3.20
8.	BS2'''	1.80	1.79	1.78	1.78	3.00	3.00
9.	BS3	1.83	1.80	1.80	1.80	3.30	3.20
10.	BS3'	1.81	1.80	1.80	1.80	3.20	3.20
11.	BS3''	1.80	1.80	1.80	1.80	3.20	3.20
12.	BS3'''	1.83	1.82	1.81	1.81	3.30	3.28
13.	BS4	1.84	1.84	1.84	1.82	3.30	3.30
14.	BS4'	1.83	1.80	1.80	1.80	3.30	3.20
15.	BS4''	1.80	1.80	1.80	1.80	3.30	3.22
16.	BS4'''	1.82	1.80	1.80	1.80	3.28	3.20

Table No.06: Gradation of "Group BS" RAP

IS sieve (mm)	Mid Point of Cumulative percentage by weight of total aggregate passing		
	RAP BS	BC	DBM
45	100	100	100
37.5	98	100	95
26.5	85	100	78
19	82	100	-
13.2	73	95	65
9.5	71	79	-
4.75	58	62	46
2.36	40	50	35
1.18	38	41	-
0.6	20	32	-
0.3	18	23	14
0.15	12	16	-
0.075	5	7	5
0.00	0	0	0



Plot No. 02: Gradation pattern of "Group BS" RAP

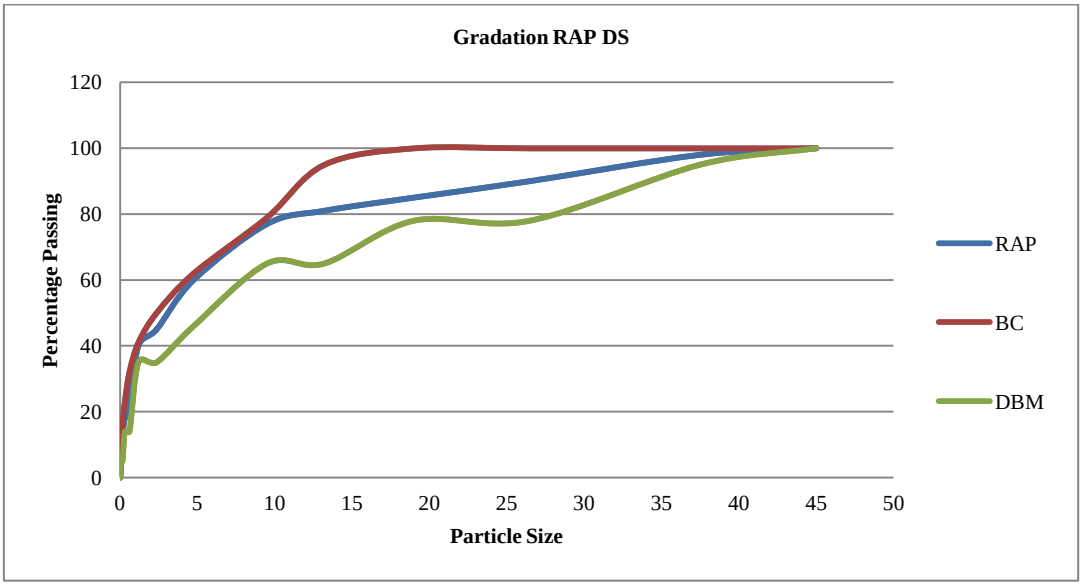
C."Group DS" RAP: These are RAP samples collected from the deteriorated pavement sites where initially bituminous layer is Semi Dense Bituminous Concrete (SDBC) over layer of Dense Bituminous Macadam (DBM) supported by a granular base. In Practice these types of RAP samples are available at Other District Roads (ODR), Major District Roads (MDR) and State Highway (SH) where initial CVPD after construction is up to 2.0 to 5.0 msa. Characteristics of this group are presented by table no.07& 08 and plot no.03.

Table No. 07: Density and bitumen content characteristics of "Group DS"

Sl. No.	Sample Code	Field Density			Lab Density	Bitumen Content	
		Sand Replacement	Non Nuclear Density Gauge	Nuclear Density Gauge		Extraction	Ignition
1.	DS1	1.96	1.96	1.96	1.96	3.90	3.90
2.	DS1'	1.96	1.95	1.95	1.95	3.88	3.86
3.	DS1''	1.97	1.96	1.96	1.96	3.90	3.88
4.	DS1'''	1.98	1.97	1.96	1.96	3.90	3.90
5.	DS2	1.96	1.96	1.95	1.95	3.87	3.87
6.	DS2'	1.98	1.97	1.97	1.96	3.90	3.89
7.	DS2''	1.97	1.97	1.96	1.96	3.89	3.88
8.	DS2'''	1.95	1.94	1.94	1.94	3.90	3.90
9.	DS3	1.96	1.96	1.96	1.96	3.90	3.90
10.	DS3'	1.96	1.96	1.96	1.96	3.90	3.90
11.	DS3''	1.99	1.98	1.98	1.97	3.89	3.87
12.	DS3'''	1.96	1.96	1.96	1.96	3.92	3.90
13.	DS4	1.97	1.96	1.96	1.96	3.90	3.89
14.	DS4'	1.96	1.95	1.96	1.95	3.91	3.90
15.	DS4''	1.96	1.96	1.96	1.96	3.92	3.90
16.	DS4'''	1.96	1.96	1.96	1.96	3.90	3.90

Table No.08: Gradation of "Group DS" RAP

IS sieve (mm)	Mid Point of Cumulative percentage by weight of total aggregate passing		
	RAP DS	BC	DBM
45	100	100	100
37.5	98	100	95
26.5	90	100	78
19	85	100	-
13.2	81	95	65
9.5	77	79	-
4.75	60	62	46
2.36	45	50	35
1.18	40	41	-
0.6	22	32	-
0.3	18	23	14
0.15	13	16	-
0.075	7	7	5
0.00	0	0	0



Plot No. 03: Gradation pattern of "Group DS" RAP

D. "Group DB" RAP: These are RAP samples collected from the deteriorated pavement sites where initially bituminous layer is Bituminous Concrete (BC) over layer of Dense Bituminous Macadam (DBM) supported by a granular base. In Practice these types of RAP samples are available at State Highway (SH) and National Highway (NH) where initial CVPD after construction is more than 5.0 msa. Characteristics of this group are presented by table no.03& 04 and plot no.02.

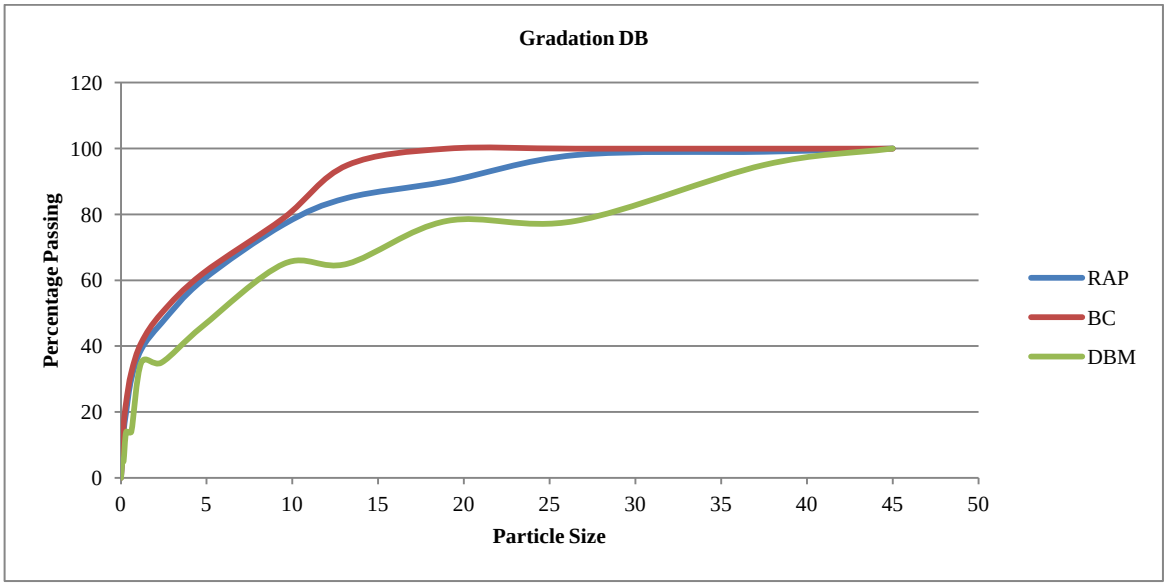
Figure 04: Bitumen Extraction, Bitumen Content Furnace and Gradation of (RAP)

Table No. 09: Density and bitumen content characteristics of "Group DB"

Sl. No.	Sample Code	Field Density			Lab Density	Bitumen Content	
		Sand Replacement	Non Nuclear Density Gauge	Nuclear Density Gauge		Extraction	Ignition
1.	DB1	1.97	1.97	1.97	1.97	4.1	4.1
2.	DB1'	1.98	1.97	1.97	1.97	4.2	4.1
3.	DB1''	1.99	1.98	1.97	1.97	4.2	4.1
4.	DB1'''	1.97	1.97	1.96	1.96	4.0	3.8
5.	DB2	1.99	1.98	1.98	1.97	4.1	4.0
6.	DB2'	1.98	1.98	1.97	1.97	4.2	4.1
7.	DB2''	1.97	1.97	1.97	1.97	4.1	4.1
8.	DB2'''	1.96	1.96	1.96	1.96	4.0	3.9
9.	DB3	1.98	1.98	1.97	1.97	4.1	4.1
10.	DB3'	1.97	1.97	1.97	1.97	4.2	4.1
11.	DB3''	1.99	1.98	1.98	1.97	4.1	4.0
12.	DB3'''	1.96	1.96	1.95	1.95	3.9	3.8
13.	DB4	1.97	1.97	1.97	1.97	4.2	4.1
14.	DB4'	1.98	1.97	1.97	1.97	4.2	4.1
15.	DB4''	1.99	1.98	1.97	1.97	4.1	4.1
16.	DB4'''	1.97	1.97	1.96	1.96	4.1	4.0

Table No.10: Gradation of "Group DB" RAP

IS sieve (mm)	Mid Point of Cumulative percentage by weight of total aggregate passing		
	RAP DB	BC	DBM
45	100	100	100
37.5	99	100	95
26.5	98	100	78
19	90	100	-
13.2	85	95	65
9.5	77	79	-
4.75	60	62	46
2.36	47	50	35
1.18	39	41	-
0.6	30	32	-
0.3	20	23	14
0.15	14	16	-
0.075	7	7	5
0.00	0	0	0



Plot No. 04: Gradation pattern of "Group DB" RAP

Initial weighted mean characteristics of different rap group are calculated in proportion of different layer thickness in RAP samples. These weighted mean parameters are given in table no. 11. Results will be compared with these initial parameters or characteristics.

Table No.11: Gradation of "Group DB" RAP

Sl.	RAP Group	First Layer BM/DBM			Second Layer SDBC/BC			Weighted Mean Characteristics Initially	
		Thickness	Density gm/cc	Bitumen Content %	Thickness	Density gm/cc	Bitumen Content %	Density gm/cc	Bitumen Content%
1.	Group PS	OGPC 20	2.00	3.5	OGPC 20	2.00	3.5	2.00	3.5
2.	Group BS	BM 50	2.20	3.5	SDBC 25	2.30	5.00	2.23	4.00
3.	Group DS	DBM 75	2.30	4.5	SDBC 25	2.30	5.00	2.30	4.63
4.	Group DB	DBM 100	2.30	4.5	BC 40	2.35	5.4	2.31	4.76

VII. RESULTS AND DISCUSSION:

On the basis of this experimental study results are summaries in table no. 12

Table No.12: Gradation of "Group DB" RAP

Sl.	RAP Group	Characteristics of RAP				Remarks
		In-Situ/Field Density	Lab Density	Bitumen Content	Gradation	
1.	Group PS	1.59	1.58	2.68	Somewhere in between DBM and BC as shown in Plot no. 01	Residual In-situ, Lab density and Bitumen Content are 79.5%, 79% and 76.6% of initial weighted mean density and bitumen content respectively.
2.	Group BS	1.79	1.78	3.13	Somewhere in between DBM and BC as shown in Plot no. 02	Residual In-situ, Lab density and Bitumen Content are 80.27%, 79.82% and 78.25% of initial weighted mean density and bitumen content respectively.
3.	Group DS	1.96	1.96	3.89	Somewhere in between DBM and BC as shown in Plot no. 03	Residual In-situ, Lab density and Bitumen Content are 85.22%, 85.22% and 84.02% of initial weighted mean density and bitumen content respectively.
4.	Group DB	1.97	1.97	4.07	Somewhere in between DBM and BC as shown in Plot no. 04	Residual In-situ, Lab density and Bitumen Content are 85.28%, 85.28% and 85.50% of initial weighted mean density and bitumen content respectively.

On the basis of this experimental results tabulated above it is noticed that:

(1) Field density calculated by three methods i.e. Sand replacement; Non- nuclear density gauge and Nuclear density gauge are more or less same. Any minute difference may be due to errors in equipment or manmade procedural mistakes.

(2) Lab density is found slightly lower in most of the cases due to loss of lateral confinement during core cutting and due to accurate testing in ideal condition of laboratory.

(3) It is found that loss in density annd bitumen content of bituminous layer decreases with increase in superiority of initial bituminous layer i.e. RAP group PS, BS, DS and DB are in sequence of increasing superiority and decreasing loss in density and bitumen content, it seems this result pattern is due to closest grading and less weathering effects in superior layers.

(4) Gradation Pattern of Different group of RAP shows that aggregate grading is coarser than Bituminous Concrete. Gradation pattern also indicates that sizes of RAP aggregates lies somewhere between aggregate sizes of initial bituminous base and wearing course. it is due presence of aggregate of bituminous base in RAP samples.

VIII. CONCLUSION:

This experimental study indicates that different groups of Reclaimed Asphalt Pavement (RAP) have significant in-situ density at location where bituminous layer is intact. It also indicates that RAP samples have significant quantity of aged binder/ bitumen content, but aged bitumen may loss it's properties hence proper study of aged recovered bitumen with and without appropriate Rejuvenators is required before recycling of bituminous layer. It is clear that Reclaimed Asphalt Pavement (RAP) can be used as a substitute of virgin pavement construction materials in different proportions which will intend to break on depletion of sources of pavement construction materials.

ACKNOWLEDGMENT:

The authors are thankful to Integral University, Lucknow for acknowledging this paper with MCN; and providing facilities within campus to carry out this research work.

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