PAVEMENT RECYCLING WITH RECYCLED ASPHALT PAVEMENTS WITH PORTLAND CEMENT

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THESIS

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CERTIFICATE OF RESEARCH

This is to certify that this thesis work has been done by our group of three members and neither this thesis nor any part of thereof has been submitted elsewhere for the award of any degree or diploma.

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Abstract

Now the cost of building a pavement day is very high as the materials are so costly. So by recycling materials we can use existing pavement materials. Reuse and recycling are the most preferred option from an ecological point of view than others.

Recent advances make it possible to reuse products from damaged layers in the manufacturing process of asphalt concrete. Because of recycling methods, it uses lower non-renewable resources. When RAP is used in base and sub-base systems, there is a potential for significant economic benefits. Approximately 30 percent could be achieved in material cost savings.

This research was undertaken to address the concerns about the effects of RAP and to evaluate the correct percentage of Recycling Asphalt Pavement, and a literature review was performed and presented as a first step.

This study summarizes the long-term quality of pavement construction projects where the concrete system has been used for Full Depth Reclamation. Overall, the Full Depth Reclamation's quality with cement was excellent.

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Chapter 1

Introduction

1.1 What is FDR

Full-depth reclamation (FDR) of asphalt pavement is a method of rehabilitation involving the recycling into a new base layer of an existing asphalt pavement and its underlying layers.

Full Depth Reclamation begins with the use of a road reclaimer to pulverize an existing asphalt pavement and a portion of the base, sub-base and/or sub-grade. Usually the pulverized material is uniformly mixed to provide an upgraded, homogeneous material with additional stabilizing material such as Portland cement.

As the infrastructure of the nation ages, it is the responsibility of agencies at all levels to maintain and rehabilitate their infrastructure. Although budgets are declining, building costs are increasing; the complete removal and reconstruction of existing pavements is becoming more costly. Furthermore, as sustainable building practices come to the fore, agencies want to recapitalize their investments in decades-old pavements by cost-effectively reusing existing materials on site.

Sustainable pavement restoration technology innovations, such as full-depth reclamation (FDR), could be the solution for organizations looking to provide high-quality services for residents while being good stewards of public funds.

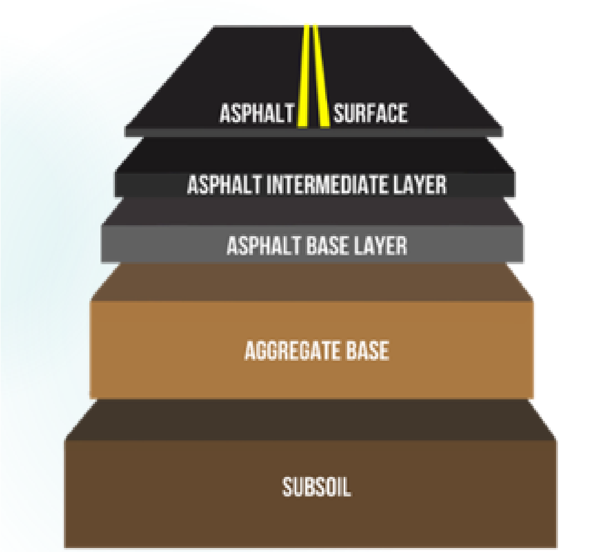


Fig : Conventional built-up granular structure

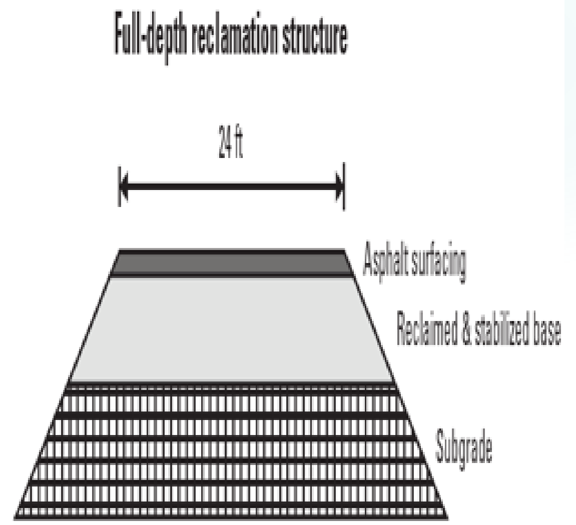


Fig : Full-depth reclamation structure

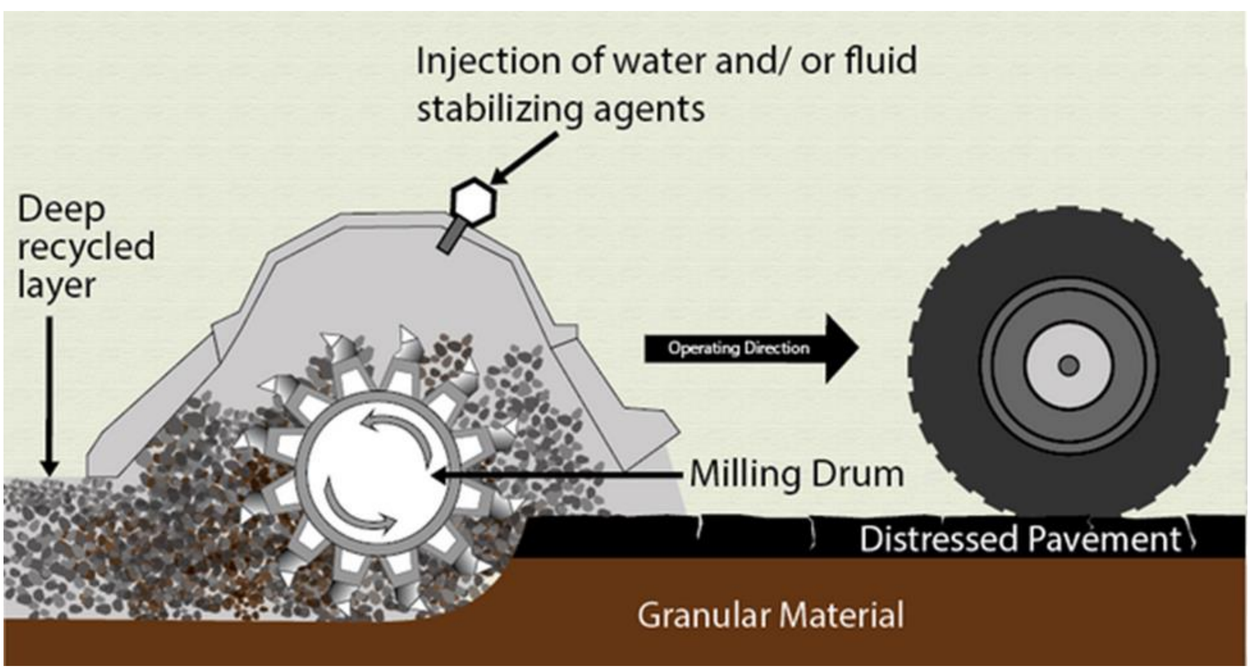


Figure : Conventional built-up granular structure (https://www.bedrockstabilization.com/services/full-depth-reclamation)

The FDR process starts with the use of a road reclaimer to pulverize an existing asphalt pavement and subgrade a portion of the base. The result is a rigid, stabilized base ready for a new course of rigid or flexible surface.

1.2 What is Recycling Asphalt Pavements (RAP)

Reclaimed asphalt pavement (RAP) is defined as removed asphalt and aggregate pavement materials. These materials are generated for reconstruction, resurfacing, or access to buried utilities when asphalt pavements are removed. RAP consists of high-quality, well-graded asphalt-coated aggregates when properly crushed and screened.

There are well-recognized financial and environmental benefits of using RAP material. Although most of the generated RAP is reused, when used in landfills, embankments or base layers, a large portion of it is wasted or downgraded.

In the transport industry, recycling of asphalt pavement has become a common practice. Recycling motives usually involve ecological, cultural, and social advantages.

The use of reclaimed asphalt pavement (RAP) in road construction is consistent with the global target of sustainable development through the responsible use of natural resources. RAP recycling activities address issues related to increasing the use of diminishing virgin aggregate supplies and product processing and disposal from paving projects of recycled asphalt material.

In addition, energy savings can be achieved by using RAP in road construction by reducing the processing and transportation of virgin aggregate materials.

Chapter 2

Benefits Of Full Depth Reclamation (FDR) :

Full-depth reclamation has numerous benefits, including the following:

- Cost-effectiveness
- Improved structural strength
- Increased reliability (as opposed to granular base materials)
- Improvement of road geometry
- Short construction timeline and enhanced staging
- Early traffic opening
- Reduced public impact during construction
- Reduced carbon footprint

2.1 Increased Structural Capacity

Full-depth concrete reclamation enhances the current roadway's structural potential by offering a stronger and more stable foundation. The pulverized, reinforced and compacted layers of asphalt and subsurface become a new roadway foundation with an enhanced structural strength. The thickness of the new surface course can be reduced with a cement-stabilized FDR base.

2.2 Stress Distribution

FDR's strong uniform support with cement leads to reduced stresses on the subgrade, especially when the surface course is asphalt. Indeed, a thinner cement-stabilized FDR layer can reduce subgrade stress more than a thicker base layer of untreated aggregate.

This reduces subgrade failures, potholes, and roughness of the road. The slab-like properties of cement-stabilized FDR bases and their beam strength are unmatched by granular bases, which can fail when aggregate interlock is lost.

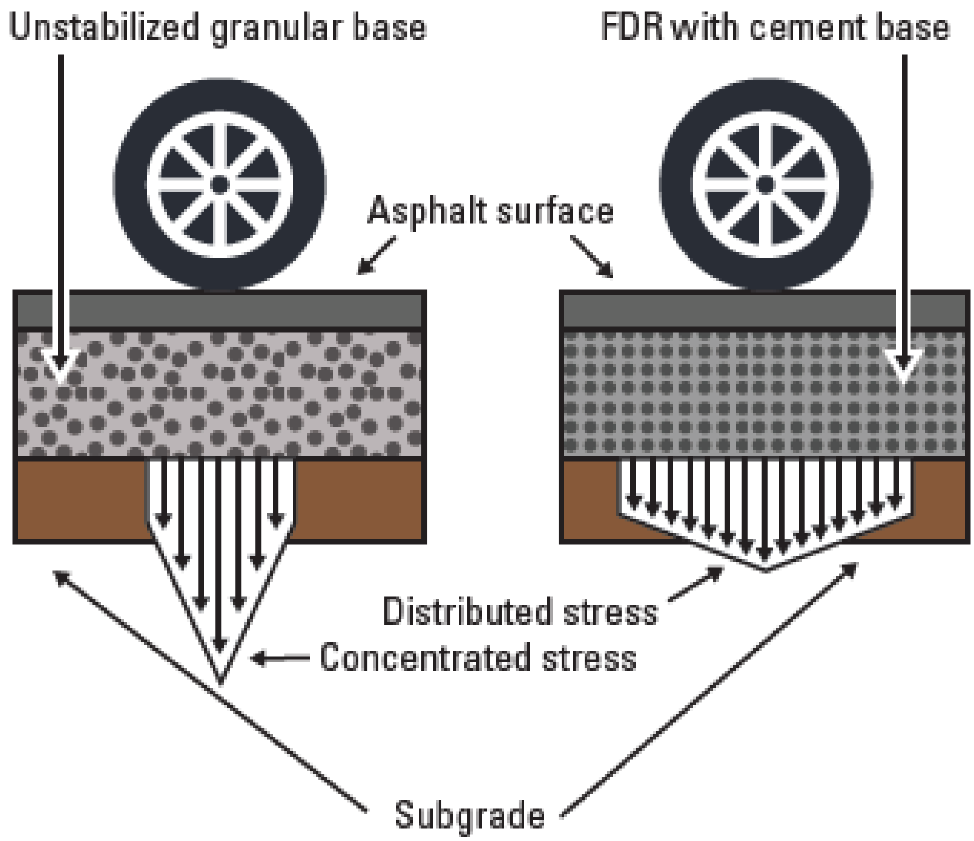


Figure : Unstabilized asphalt base results in more concentrated stress on the subgrade than FDR with cement.

2.3 Reduce Deflections

The stiffer base reduces deflections due to traffic loads compared to an unstable granular base, resulting in lower stresses in an asphalt surface. This delays the onset of surface distress, such as cracking fatigue, and extends the life of pavement.

The cement-based FDR decreases cracking fatigue compared to an unstable foundation and makes it more durable.

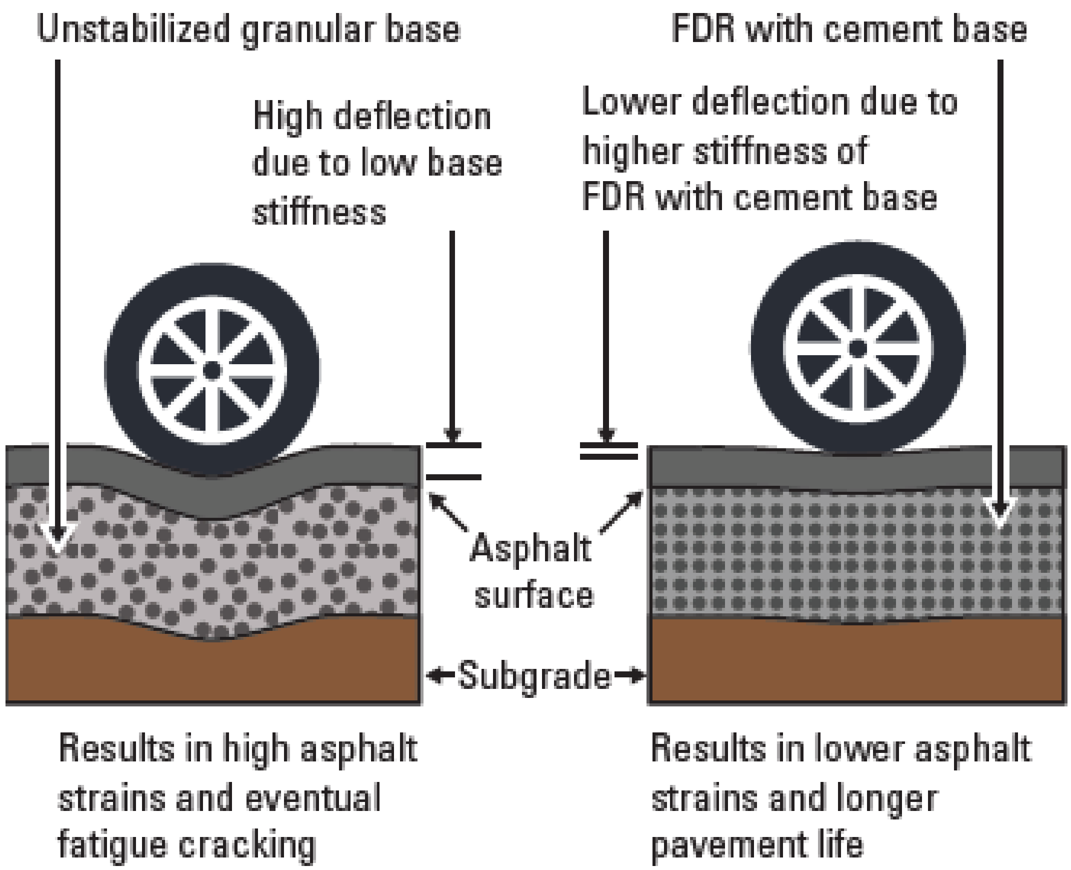


Figure : FDR with cement base reduces fatigue cracking compared to an unstabilized base.

2.4 Cost effectiveness

Full-depth reclaiming also reduces the quantity of new material to be transported to the site compared to methods requiring the transportation of granular material to the site. Through reducing the effort involved in extracting and disposing existing material and in shipping and placing new material, FDR saves time and money, decreasing the cost of transportation and labor relative to the methods of removal and replacement.

2.5 Advantages and Disadvantages

Solution	Advantages	Disadvantages
Thick structural overlay	• Provides new pavement structure • Fast construction • Only moderate traffic disruption	• Large quantity of material must be imported • Old base/subgrade may still need improvement • High cost alternative • Elevation change can present problems for existing curb and gutter and overhead clearance
Removal and replacement	• Provides new pavement structure • Failed base and subgrade are eliminated • Existing road profile/elevation can be maintained	• Long construction cycle requiring detours and inconvenience to local residents/business • Increased traffic congestion due to detours, construction traffic • Rain or snow can significantly postpone completion • Large quantity of materials must be imported • Old materials must be properly disposed • Highest cost alternative • May require additional effort to correct subgrade problems • Significant carbon footprint
Recycling surface, base, and subgrade with cement (full-depth reclamation)	• Provides new pavement structure • Fast construction cycle • Only moderate traffic disruption • Minimal change in elevation, thus eliminating problems with curb and gutter, overhead clearances • Minimal material transported in or out • Conserves resources by recycling existing materials • Local traffic returns quickly • Rain does not affect construction schedule significantly • Provides moisture-and frost -resistant base • Least cost alternative • Requires thinner surface course than traditional construction methods	• May require additional effort to correct subgrade problems • Some shrinkage cracks may reflect through bituminous surface

Table : Comparison of Pavement Rehabilitation Strategies

Chapter 3

Review Of Existing Literature :

3.1 Synopsis of Research Studies

Full-depth reclamation with cement is a self-sustaining process for roadway reconstruction. The original investment in virgin road materials can be reused by pulverizing and reclaiming with cement stabilization. Full-depth reclamation saves money and reduces the carbon footprint of roadway construction projects by reducing mining, hauling, and disposal of basic construction materials. [1]

There is a potential for significant economic benefits if RAP is used in base and sub-base applications. Approximately 30% in material cost savings could be realized with a 50/50 blend of RAP and virgin aggregate. In addition, this application would likely result in a substantial reduction in the amount of RAP material currently stockpiled in Virginia. [2]

The FDR with cement process is popular with state and local agencies trying to maintain their highway network in the face of shrinking budgets. The economics of the FDR with cement process has helped the highway agencies reconstruct 50% to 100% more projects than the conventional construction process. [3]

The asphalt industry is considered number-one recycler and in 2012 almost all (98%) contractors in the United States reported using RAP with estimated savings of $2.04 billion at $600 per ton for asphalt binder [4].

3.2 Synopsis of Publications

The stiffness strength properties tests showed the RAP had stiffness strength higher than an unbound traditional used base [5]

The cement treated base is efficient alternative of the subbase material in flexible pavement.[6] The using of CTB, binder and surface course presents the best economical choice of pavement structure [6]

Higher percentages (e.g. >50%) are being adopted to save money and natural resources. [7]

Item	Cost per ton ($)	Percent used (%)	Total Cost ($) per ton
Aggregate	5.00	94	4.70
Asphalt Binder	120.00	6	**7.20**
Virgin Mix			11.90
RAP			
Trucking	2.00		2.00
Milling	1.70		**1.70**
RAP Mix			3.70
Savings in using 1 ton of RAP instead of 1 ton of virgin mix			8.20

Figure : Comparison of cost for virgin and RAP mix (https://www.fhwa.dot.gov/pavement/recycling/98042/04.cfm)

The unconfined compressive strength (UCS) of FDR with cement bases is typically higher than that of other stabilized base methods such as asphalt emulsions, lime, or fly ash. [7]

RAP increased the stiffness of asphalt mixes, thus improving rutting resistance at high temperature. [7]

There is a potential for significant economic benefits if RAP is used in base and subbase applications. [8]

FDR with Portland cement is not more susceptible to moisture intrusion when compared with a compacted RAP base [9]

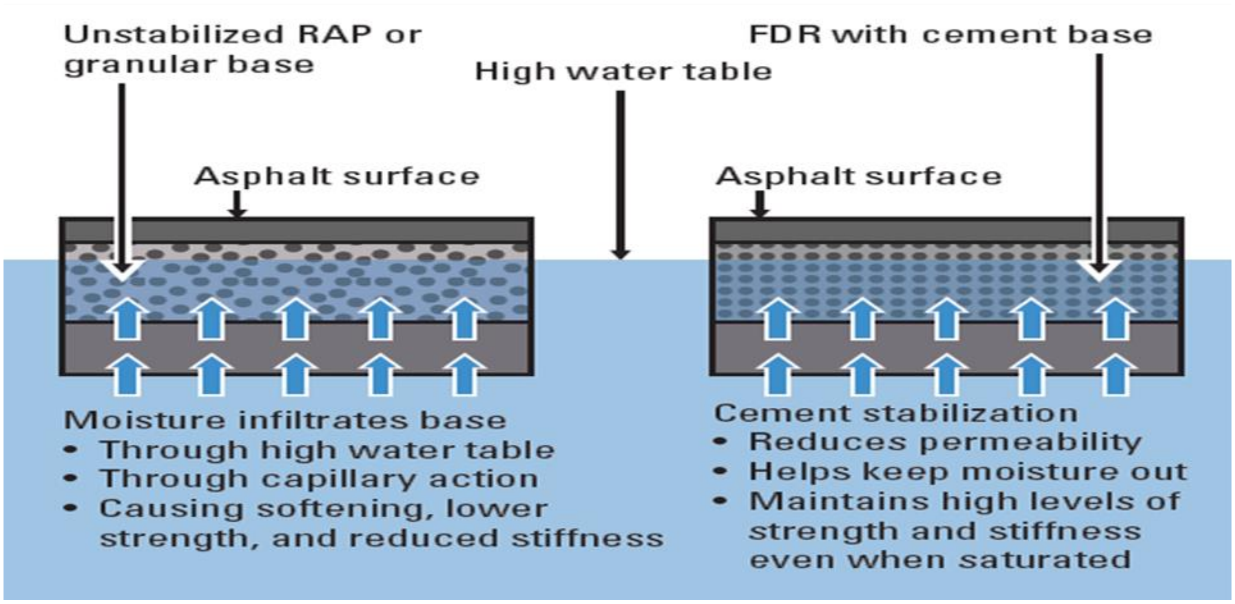


Figure : Guide to Full-Depth Reclamation
(https://cncement.org/guide-to-full-depth-reclamation-fdr-with-cement)

A study by found that using RAP as an unbound aggregate base course was a suitable alternative approach, where the stiffness strength properties tests showedthe RAP had stiffness strength higher than an unbound traditional used base and had a slightly higher permeability [10]

Chapter 4

Methodology

4.1 Material Used

Portland Cement : We use Portland Cement in accordance with Specification 5.11, CEM type-01 of Portland Cement. Unless otherwise directed or approved by the Consultant Normal Type 10 Portland Cement shall be used.

Aggregates : Both fine and coarse aggregate was used in our experiment. We used aggregate in accordance with Specification 3.2, Aggregate Production and Stockpiling, for the designation and class of material specified.

Coarse Aggregate : We used recycled sub-base materials which is mainly solid stone type collected directly from road full depth reclamation. From ASRM C-33 guidelines we got the % finer range of the maximum density curve.

Figure : Recycling Asphalt Materials

Figure : Virgin Material

Table : Determining % retain value of coarse aggregate based on ASTM C-33

Maximum Aggregate Size 37.5 mm (Size No. 467) (ASTM C-33)					
Sieve Opening	Lower Limit	Higher Limit	% Finer	Cum. % Retain	% Retain
50	100	100	100	0	0
37.5	95	100	97.5	2.5	2.5
19	35	70	52.5	47.5	45
9.5	10	30	20	80	32.5
4.75	0	5	0	100	20

From there, we have taken % finer value of different size aggregate within the range and calculate the % retain value and according to mix design we use this % retain value for different size aggregates.

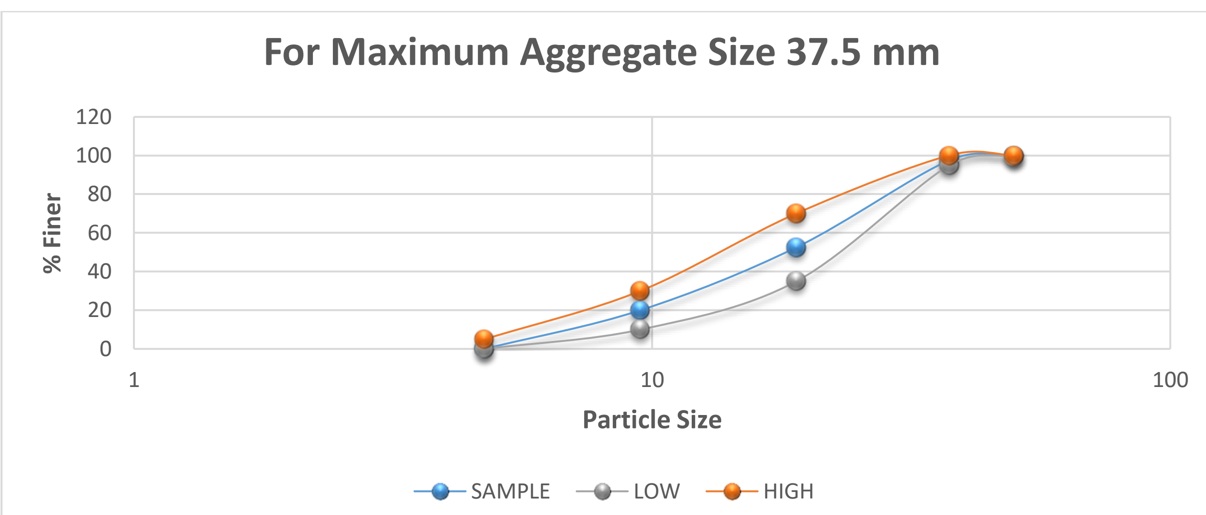


Figure : Coarse Aggregate % finer in the range according to ASTM C-33

Fine Aggregates : Used normal available lab sands as fine aggregate which FM was **2.46**. This is fine graded sand. We measure the amount of sand correctly and use it According to mix design.

Table : Determining % retain value of fine aggregate based on ASTM C-33

Sieve Opening	Lower Limit	Higher Limit	% Finer	Cum. % Retain	% Retain
9.5	100	100	100	0	0
4.75	95	100	99.5	0.5	0.5
2.36	80	100	90	10	9.5
1.18	50	85	80	20	10
0.6	25	60	50	50	30
0.3	5	30	25	75	25
0.15	0	10	10	90	15

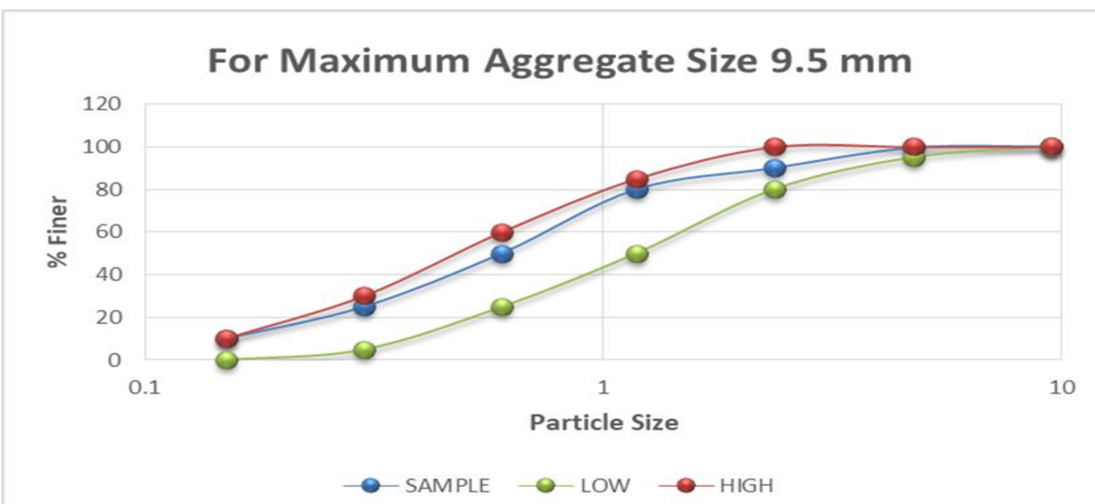


Figure : Fine Aggregate % finer in the range according to ASTM C-33

Water : We Used nomal tap water with proper water-cement ratio suggested from mix design. We take the amount of water accurately according to the mix design.

4.2 Equipments & Apparatus :

Mixture Machine, Weight Machine, Compressometer-Extensometer, Hammer, Scale, Compression Testing Machine, Oven.

4.3 Working Procedure :

Oven Dry :

We have oven dried both of coarse and fine aggregate almost 24 hours. It was needed because of the accuracy of sieve analysis. We set the temperature of oven too high so that the aggregate could dried accurately.

Sieve Analysis :

We used mainly 37.5 mm , 25 mm , 9.75 mm & 4.75 mm as our coarse aggregate and 9.5 mm, 4.75 mm, 2.36 mm, 1.18 mm, 0.6 mm, 0.3 mm , 0.15 mm sieve size distribution as our fine aggregate.

Mixing of Aggregate :

1. We have used 100 % recycled aggregate as coarse aggregate.
2. Then we have used 60 % recycled aggregate and 40 % normal available laboratory aggregate as coarse aggregate.
3. Then we have used 30 % recycled aggregate and 70 % normal available laboratory aggregate as coarse aggregate.
4. At last we used full 100 % recycled aggregate.
5. Cement to be mixed with the sand or gravel material shall be uniformly distributed throughout the material during the mixing operation.
6. Sand or gravel, cement and water shall be mixed such that an homogeneous mixture, uniform in gradation, cement content, moisture content and appearance is attained

Casting :

1. According to mix design we used accurate amount of sand, cement and water for casting.
2. We have made cylinders of specific volumes.
3. We used mixture machine for casting.
4. Proper tamping of 3 layers each of 25 blows was done
5. Hammering, scaling was also ensured.
6. We ensured smoother upper surface.

Figure : Cylinders after casting

Curing :

1. We have ensured that all the cylinders were well drowned in water.
2. We have kept the cylinders about 14days.

Test Procedure :

Controlled Compressive strength test was carried out with 101.7 *101.6*200 mm cylindrical mold. The test temperature was 25°C.

Compressometer-extensometer was used to hold the cylindrical mold for testing purpose. It is a very vulnerable and costly device.

Slide calipers & scales were used to measure the dimensions of the cylinder.

Compression testing machine was used to break the cylinder and measure the compressive strength of the cylinders. We carefully set zero in the arial deformation dial gauge. Also taken the readings steadily.

Figure : Compression testing machine to determine Compressive strength

Figure : Compressometer-Extensometer

<u>Data Collection & Mix design :</u>

We followed this mix design for preparing cylenders. Proper portion of fine aggregate, coarse aggregate, cement & water is determined by these mix design.

Table : Mix Design for casting procedure

MIX Design							
Case	Cement Type	W/C	S/A	Cement Content W_c kg/m3	Water Content W_w kg/m3	Fine Aggregate W_{FA} kg/m3	Coarse Aggregate W_{CA} kg/m3
P1	OPC	0.45	0.5	400	180	704.5161	916.3291

Table : Mix Design for four cylinder we used

MIX DESIGN PER CASE				
No of Cylinder Needed Per Case	Cement Content W_c (kg)	Water Content W_w (kg)	Fine Aggregate W_{FA} (kg)	Coarse Aggregate W_{CA} (kg)
4	2.75	1.24	4.84	6.29

Oven Dry	SSD	Wt in Water
2.73	2.758	1.7585

Absorptn Capacity %	1.025641026

Spc. Grav. Cement	3.1
Spc. Grav. CA	2.73136568
Spc. Grav. FA	2.46
γ_w	1000
y	670.967742
Volume of a cylinder	0.00171597

Specific Gravity of Coarse Aggregate = Oven Dry Wt/(SSD Wt – Wt in Water)

Absorption Capacity = (SSD Wt – Oven Dry Wt)*100/Oven Dry Wt

<u>This is the calculation for 0% RAP using coarse aggregate needed per mix design :</u>

Maximum Aggregate Size 37.5 mm (Size No. 467) (ASTM C-33)													
Sieve Opening	Lower Limit	Higher Limit	% Finer	Cum. % Retain	% Retain	Form Mix Design	For 6.29 Mix CA Need (kg)	RAP Used in (kg)	Other Stone Used (kg)	RAP Used (%) Per Size	Other Stone Used (%) Per Size	Total RAP Used (%)	Total Other Stone Used
50	100	100	100	0	0	We found, Coarse Aggregate Needed = 6.29 KG	0	-	-	-	-	0	100
37.5	95	100	97.5	2.5	2.5		0.15725	0	0.15725	0	100		
19	35	70	52.5	47.5	45		2.8305	0	2.8305	0	100		
9.5	10	30	20	80	32.5		2.04425	0	2.04425	0	100		
4.75	0	5	0	100	20		1.258	0	1.258	0	100		
						SUM =	**6.29**	**0**	**6.29**				

This is the calculation for 30% RAP using coarse aggregate needed per mix design :

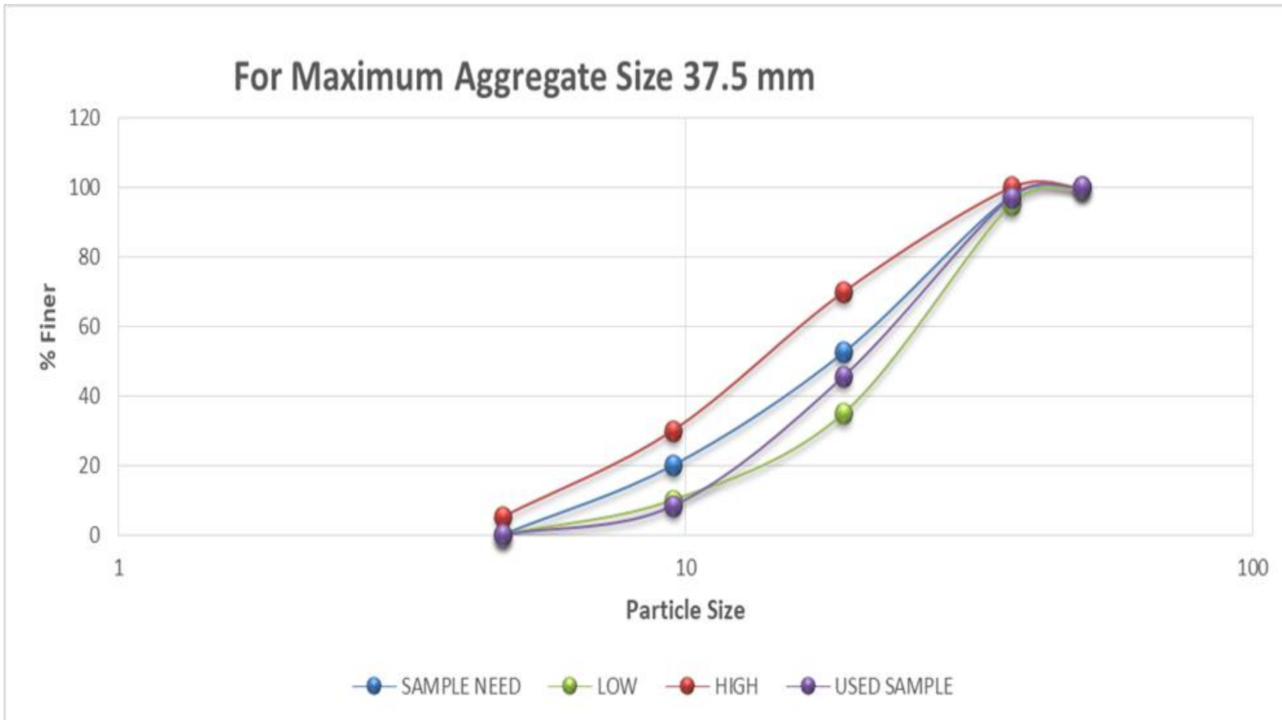
Maximum Aggregate Size 37.5 mm (Size No. 467) (ASTM C-33)													
Sieve Opening	Lower Limit	Higher Limit	% Finer	Cum. % Retain	% Retain	Form Mix Design	For 6.29 Mix CA Need (kg)	RAP Used in (kg)	Other Stone Used (kg)	RAP Used (%) Per Size	Other Stone Used (%) Per Size	Total RAP Used (%)	Total Other Stone Used
50	100	100	100	0	0	We found, Coarse Aggregate Needed = 6.29 KG	0	-	-	-	-	30	70
37.5	95	100	97.5	2.5	2.5		0.15725	0.047175	0.110075	30	70		
19	35	70	52.5	47.5	45		2.8305	1.1322	1.6983	40	60		
9.5	10	30	20	80	32.5		2.04425	0.613275	1.430975	30	70		
4.75	0	5	0	100	20		1.258	0.09435	1.16365	7.5	92.5		
						SUM =	**6.29**	**1.887**	**4.403**				

This is the calculation for 60% RAP using coarse aggregate needed per mix design :

Maximum Aggregate Size 37.5 mm (Size No. 467) (ASTM C-33)													
Sieve Opening	Lower Limit	Higher Limit	% Finer	Cum. % Retain	% Retain		For 6.29 Mix RAP Need (kg)	RAP Used in (kg)	Other Stone Used (kg)	RAP Used (%) Per Size	Other Stone Used (%) Per Size	Total RAP Used (%)	Total Other Stone Used
50	100	100	100	0	0	Form Mix Design We found, Coarse Aggregate Needed = 6.29 KG	0	-	-	-	-	60	40
37.5	95	100	97.5	2.5	2.5		0.15725	0.09435	0.0629	60	40		
19	35	70	52.5	47.5	45		2.8305	2.2644	0.5661	80	20		
9.5	10	30	20	80	32.5		2.04425	1.22655	0.8177	60	40		
4.75	0	5	0	100	20		1.258	0.1887	1.0693	15	85		
						SUM =	**6.29**	**3.774**	**2.516**				

This is the calculation for 100% RAP using coarse aggregate needed per mix design :

Sieve Opening	Lower Limit	Higher Limit	% Finer	% Finer USED	Cum. % Retain	Cum. % Retain USED	% Retain	% Retain USED	Form Mix Design We found, Coarse Aggregat e Needed = 3.43 KG	For 3.43 Mix RAP Need (kg)	For 3.43 Mix RAP USED (kg)
50	100	100	100	100	0	0	0	0		0	0
37.5	95	100	97.5	97.1355685	2.5	2.86443149	2.5	2.86443149		0.08575	0.09825
19	35	70	52.5	45.5758017	47.5	54.4241983	45	51.5597668		1.5435	1.7685
9.5	10	30	20	8.33819242	80	91.6618076	32.5	37.2376093		1.11475	1.27725
4.75	0	5	0	0	100	100	20	8.33819242		0.686	0.286
									SUM =	**3.43**	**3.43**



In the graph we can see that our sample of 100% Reclaimed Asphalt Pavement line just went in the range of ASTM C-33 guideline. As we have shortage of very small specifically 4.75 mm recycled asphalt materials, we use 19 mm and 9.5 mm much amount and then also we found the % finer in the range of ASTM C-33 guidelines.

Chapter 5

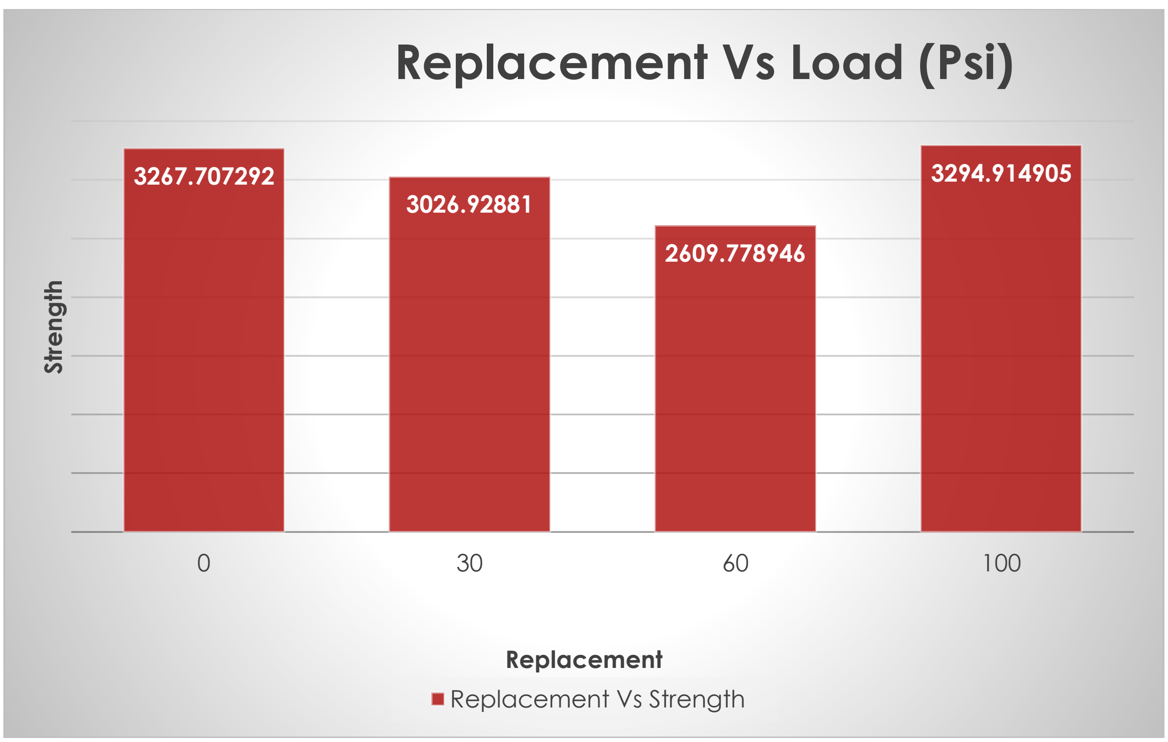
Results

Compressive strength of the available laboratory materials (0% RAP used) is found 3267.70 psi**.**

Compressive strength of the 30% RAP and 70% virgin materials is found 3026.93 psi.

The compressive strength of the 60% RAP and 40% virgin materials is found 2609.78 psi.

For 100% RAP it is found 3294.92 psi.

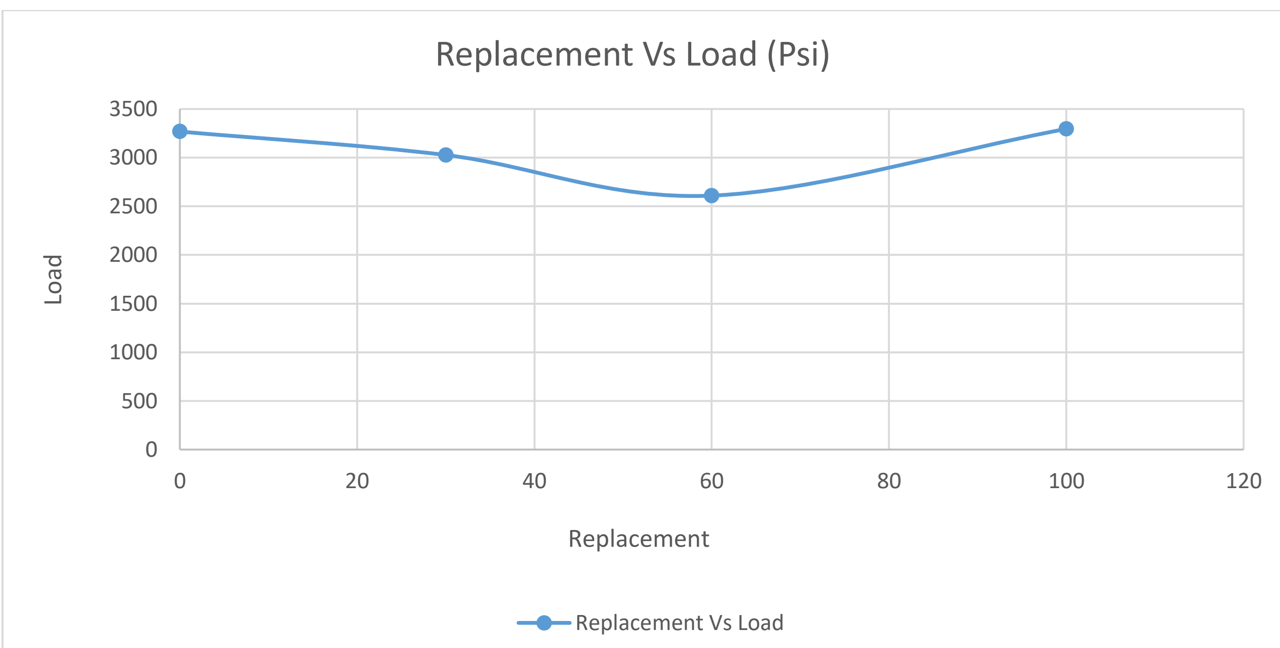


Graph : Determination of strength of cylinders (in Psi)

Table : Determination of Strength (Psi)

Replace-ment	Load of Cylender 1	Load of Cylender 2	Load of Cylender 3	Avrg Load	Wt of cylende 1	Wt of cylender 2	AVG Wt	Radius of Cylender 1	Radius of Cylender 2	AVG Radius	Area(mm^2)	Strength (Mpa)	Strength (psi)
0	197.3	186.8	164.2	182.7667	4065	4196.9	4130.95	50.83	50.8	50.815	8112.1271	22.530055	3267.7073
30	168.6	169.3	0	168.95	3989.2	4019.6	4004.4	50.75	50.775	50.7625	8095.3735	20.869945	3026.9288
60	141.3	148.6	0	144.95	4028.4	4050.5	4039.45	50.65	50.625	50.6375	8055.5538	17.993797	2609.7789
100	188.2	179	0	183.6	4003.7	3985.2	3994.45	50.8	50.64	50.72	8081.8238	22.717644	3294.9149

Strength = (Load*1000*145)/A Psi [where load in KN & area in mm^2]



Graph : Replacement Vs Load (In Psi)

Figure : 100 % RAP used cylinder compressive strength cracking

Figure : 60% RAP used cylinder compressive strength cracking

Figure : 30 % RAP used cylinder compressive strength cracking

Figure : 0% RAP used (Virgin Material) cylinder compressive strength cracking

Chapter 6

Conclusion

6.1 Discussions and Recommendation

While Portland cement Full Depth Reclaim is a powerful rehabilitation tool, not all failed flexible pavements are suitable candidates. FDR-PC pavements that have been correctly identified can provide both economic and environmental benefits. Given some failures in this process, the use of this system is growing worldwide and is one of the best alternative methods for pavement construction.

The results may vary as we cast different percentages of cylinders in different days. The importance of environmental impact and the error of calculation can also influence our performance.

We have reached a point after completing all the research work and evaluation that we can find the 30 percent substitution of coarse aggregate with recycled asphalt pavement materials to be the best among the other parameters. The compressive strength is 3026.92 psi, which is much similar to the laboratory materials available (0 percent used RAP).

From this research, we have found that homogeneous material gives a better compressive strength value. For example, the 100% recycled asphalt we used gave a better compressive strength quality. The compressive strength quality was improved in addition to the 0 percent recycled asphalt (100 percent virgin material) that we used.

We also found that nearly identical coarse aggregate types give better strength than mixing different aggregate types.

We can therefore recommend that the 100 percent RAP material and 30 percent RAP material be a good choice from an environmental and economic point of view for pavement construction.

6.2 FUTURE SCOPE OF RESEARCH

Testing strengths of the different percentage of pavement layers with Fly Ash, lime and dewatering admixtures & other additives.

Testing Tensile/shear strength of RAP using UTM Using of Fine aggregate RAP.

Testing the deformation pattern of Recycled pavement material constructed road.

Analysis of Longitudinal Cracking, Fatigue Cracking, Transverse Cracking can be done on those pavements which are made by recycled asphalt pavement.

Moisture sensitivity analysis also can be done.

Use of chemical stabilization agents performance can be observed.

Base layer and asphalt layer recycling can be done and compare the result with sub-base layers.

Acknoledgements

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