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MECHANICAL AND PERFORMANCE CHARACTERISTICS OF SEMI-RIGID MIX DESIGN WITH RECYCLED MATERIALS AND STANDARDIZATION OF RUT DEPTH MEASUREMENTS

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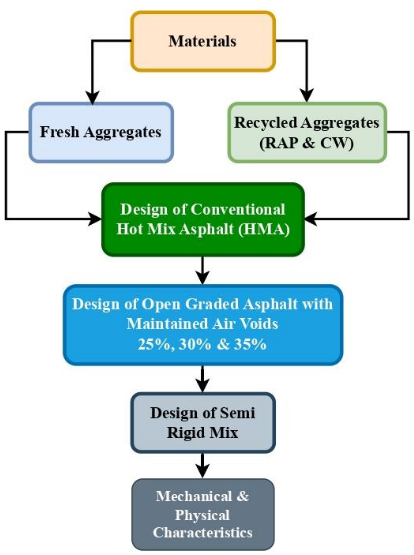
Graphical abstract



Abstract

Pavement industry requires substantial modifications in terms of materials. Stakeholders are in need to opt the solutions of semi-rigid design mix with recycled materials. Necessary evaluations in terms of experimental measures are initially required to represent characteristics properties. Moreover, the behavior to be assessed is rut depth measurements through the implications of wheel tracker apparatus and in accordance with prescribed standards. The mix with specified curing days is being differentiated through subsequent directions focusing choice of recycled materials. The paper presents a model to excel distinguished properties inclusive of the analysis for maintaining air voids, induction of grouting material and stability. The output-oriented data is justified within the enumerations of rut depths for grouted samples. It is analyzed for 25%, 30% and 35% air voids in conditioned to fresh and recycled aggregates. The deliberations are meant with 91 and 13 sample combinations of aggregates and hot mix asphalt respectively followed by the significant tests on bitumen and grouting material. It is observed that critical samples are passed in the configurations of rut depths when processed with reclaimed and construction waste materials at 35% voids. The research data entails its affectivity due to the uniqueness in superior model of current scenario.

Keywords: Pavement, Semi-Rigid, Rutting, Aggregates, Performance

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1.0 INTRODUCTION

Suitability of material in different pavements is an essential parameter. When it comes to semi-rigid pavement, this parameter is required to be accommodated in a synchronized manner. Sem-rigid pavement is one of the most effective type of pavement in which grouting action is taken into account [1]. While presenting the case of this type of pavement, the particular behavior must be kept into the mind. At most situations, semi-rigid pavement is considered as economical type but it is also required to observe the pattern of distresses that may be featured in the planned structure. Not only that, several other benefits may be considered from such type of pavement when it compares with conventional construction. In this connection, clear comparison may be established for specific types of pavements in terms to its economy, durability and nature of construction for which the idea is transformed in the study. As far as the use of semi-rigid with the recycled materials or aggregates is concerned, this option is more viable [2]. Hence, the overall study is catered with this matter. Irrespective of that, several other modifications are also available in pavement industry [3]. It is quite evident that selection of material in pavement should be in accordance with the standard specifications and in lines with the economical perspective. Implications of semi-rigid pavement with the involvement of recycled aggregates is one of the solution in this context [4]. Two major perspectives like mechanical and performance characteristics are necessary to evaluate in this connection. Mechanical characteristics are meat about the experimental properties of the mix however performance measures are monitored subsidizing rut depth of the questionable pavement. The whole study surrounds with these parameters. There are also certain advancements against cement treated layers which is composed with the variations in the percentages of cement and water contents. The applicable material is Portland cement for the same. Some studies are also derived for grouted semi-flexible pavement pertinent more towards semi-rigid pavement [5]. This type of pavement is constructed using open graded asphalt concrete followed by the grouting maneuvers of cement mortar which is normally of high fluidity [6]. In connection to the research study and customized research gaps, the relevant practitioners are required to focus the preference of other recycled materials like crumb rubber [7], recycled plastic wsate and fly ash. Suitable recycled materials are proportioned in this research while the list may be the choice of utilization in similar circumstances followed by the justified results and experimentations.

1.1 Enhancing Semi-Rigid Mix with Recycled Materials

It is a common practice that stabilized layers pattern is pre-dominated in semi-rigid pavement construction. As far as the behavior of rigid and flexible pavements are concerned, they are pertinent to load transfer mechanism and critical loaded area accordingly. Semi-rigid pavement is basically the composition of bitumen, aggregates and porous mix having 25% to 30% air voids in it. In-fact, the voids are transfused with some suitable grouting materials. Apart from that, different parameters are also included during the design phase. Likewise; fatigue life, material dislocation, resilient modulus, thickness and reliability [3]. Semi-rigid pavement with recycled materials is more pronounced for the stakeholders instead of conventional construction due to the observance of more strength and a far suitable solution in economical perspective [8]. The entire working is dependent on the efficient use of recycled materials and the applicability of the grouting material filled in the voids. Here, in this scenario, the percentage of voids and further the amount of grouting material to be filled in the grouts are important so as to idealize the stability of the mix [9]. On the contrary, somehow when it is subjected with the enhanced use of reclaimed material, a lesser amount of bitumen is accomodated in order to achieve required bitumen content. The governing parameters that may enhance the construction of semi-rigid pavement with recycled materials are construction cost requirements, load transformations, applicability of flexure, compressive and binding forces, rutting and fatigue failures [10]. Besides that, the system corresponds to the improved mechanical and performance characteristics with lesser rate of rutting as deprived with the analysis carried out and validated research methods.

1.2 Rutting Characterization in Semi-Rigid Mix Design

In order to observe the mechanical properties of semi-rigid pavement, it is advisable to understand the rutting behavior through its different types. Under normal circumstances and in lines with the conditions of Hot Mix Asphalt (HMA), there are three types of rutting. These include; mix rutting, subgrade rutting and densification. Individual behaviors are discussed below for all the types [5].

- Mix rutting implies to layer pushing in downward direction and may cause to flow away from the critical load. As a result, a bit elevation may be noticed at the wheel path.
- As the name shows, compaction of subgrade is noticed in the subgrade rutting resulting into the depression. It normally features cracked asphalt.
- Densification is more susceptible to asphalt layer due to continuous traffic loading. This is common due to the consolidation followed by shear deformations.

The overall idea is more elaborated in Figure 1 [5].

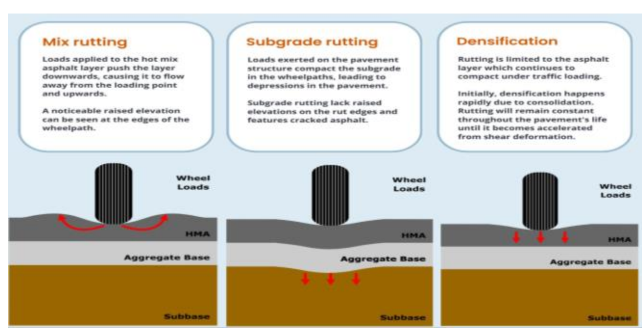


Figure 1 Rutting Behavior

1.3 Standardization for Rut Depth Measurements

There are numerous standards available which are meant to specify the rut depths. The standards are opted from available researches in which rut depths limits are specified in accordance with the pavement condition and technical characteristics. The marginal standards are set out in Table 1 [6].

Table 1 Rut Depth Measurements

Pavement Condition	Characteristics (Traffic Safety and impact on the road user)	Rut Depth Limits (mm)
Very Good	Pavement has no ruts	<5
Fair	No ruts can be observed in the pavement and there is no impact on road users	10-20
Poor	Ruts can clearly be seen in the pavement driving speeds are influenced.	20-30
Very Poor	Ruts effect traffic safety both in rain and in dry conditions	>30

On a similar note, the specifications are also derived for virgin and modified materials as per the guidelines in Table 2 [6]. In addition to that, following the standards, severity levels are also tabulated against mean rut depth in Table 3 [6].

Table 2 Rut Depth Specifications

Specifications	Virgin	Modified
ASTM D4696:	5 mm after 10,000 cycles at 100 psi in the Hamburg Wheel Tracking Test (HWTT)	2.5 mm after 10,000 cycles at 100 psi in the HWTT
AASHTO T-324	5 mm after 20,000 cycles at 75 psi in the HWTT	2.5 mm after 20,000 cycles at 75 psi in the HWTT

Table 3 Severity Levels for different Rut Depths (AASHTO, 1993)

Mean rut depth (mm), 75psi	Severity level
6–13	Low
13–25	Medium
>25	High

2.0 METHODOLOGY

The scientific analysis of the research is being carried out in technical terms holding the significant measures and standard outputs. The overall validations are taken into account keeping in view of the ASTM standards. Initially, the concerned interpretations are approached by Marshall Mix design featuring achieved blend grading. The design process is accumulated with aggregate and binder selection focusing performance evaluations. Subsequently, mix design method is interrelated with stability and fatigue checks in order to withstand with the resistive forces during the design phase. With this, prescribed air voids are maintained in the samples for respective evaluations in accordance with the design of flexible and semi-rigid pavements. Further, parametric or base properties are analyzed against fresh and recycled aggregates keeping in view to prepare its adjustable combinations. Thereafter, the average stability of the samples are investigated in lines with the uniform volumetric properties however the generated samples are experimented for with and without grouting [11]. Initially, the investigations are meant for generic materials along with grouting material. In this way, the combinations are prepared for fresh aggregates and recycled aggregates such as Reclaimed Asphalt Pavement (RAP) and Construction Waste (CW) material. It is quite evident that stabilities are monitored with the focus on curing days for example; 3 days, 5 days, 7 days and 28 days [3]. Similarly, the particular samples of aggregates, RAP, CW, bitumen and ordinary Portland cement (OPC) are derived from specific locations like Sindh Stone Crusher, Norriabad, Sindh, Pakistan, Attock Cement Pakistan Limited and Falcon Cement [3]. The locations are specified in Figure 2 and Table 4.

Figure 2 Sindh Stone Crusher, Norriabad, Sindh, Pakistan

Table 4 Location of Samples

S. No.	Samples
Fresh Aggregate	
1	Source of Aggregate Nooriabad Sindh, Sindh Stone Crusher Nooriabad
Ordinary Portland Cement	
2	Falcon Cement, Attock Cement Pakistan Limited (ACPL) Pakistan
Bitumen	
3	National Refinery Limited, Korangi Industrial Area Karachi, Pakistan
Reclaimed Asphalt Pavement (RAP)	
4	Shahrah-e-Pakistan, Near Toll Plaza Karachi, Pakistan
5	Link Road, Education City Karachi, Pakistan
6	Shahrah-e-Faisal, Near Awami Markaz, Karachi Pakistan

S. No.	Samples
Construction Waste (CW)	
7	Demolished Construction Waste, Alladin Park Karachi, Pakistan
8	Demolished Construction Waste, Nasla Tower Karachi, Pakistan
9	Demolished Construction Waste, D Block Sir Syed University Karachi, Pakistan

The reason behind the selection of samples from these locations is the reflection of proper design and construction phases on subject areas. Furthermore, grade 80/100 bitumen is utilized for the research due to observance of adequate consistency within the samples [12]. Cetainly, the concept of semi-rigid mix is integrated in accordance with the job mix formula for featuring the allowable percentage material used focusing the preparation of HMA. It is more elaborated by Figure 3.

Figure 3 Preparation of Hot Mix Asphalt (HMA), Marshall Test Samples and Grouting

On the contrary, all tests are monitored with the standrad limits in the analytical portion following the calibrated specifications however the results are also generated by earlier calibration of dedicated equipment. Moreover, considering preliminary checks for aggregates, 13 different combinations from fresh to recycled materials are accounted that are subjected to 7 lab tests making 91 tests altogether, which is assembled in Figure 4.

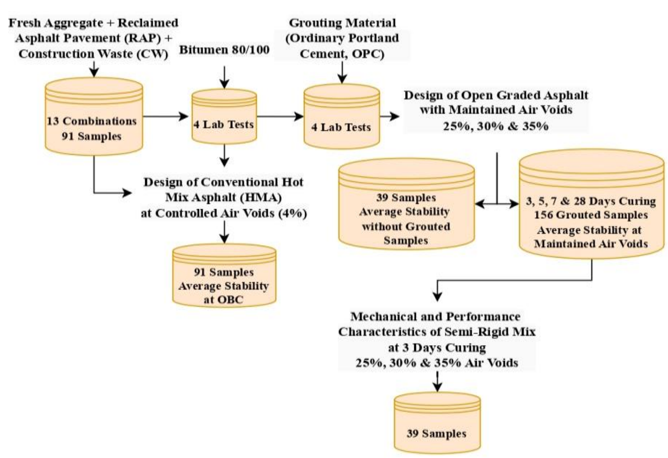


Figure 4 Sample Combinations

In order to achieve the basic aim of the research, rut depth measurements are enumerated on the prepared samples using Wheel Tracker Apparatus. The subject methodology is comprehensively organized in terms of Figure 5.

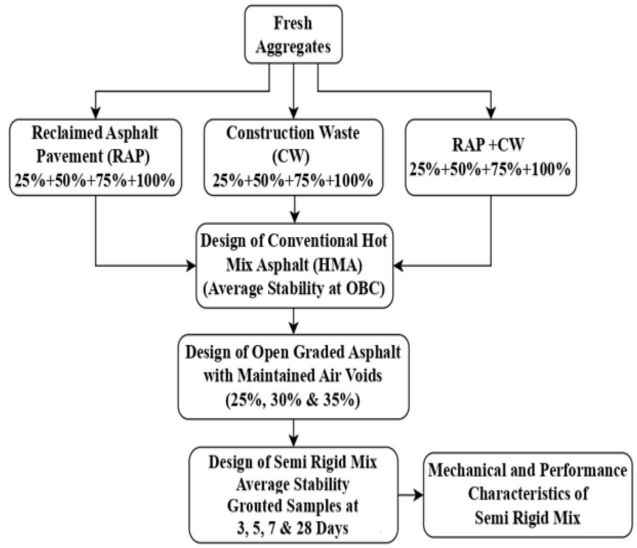


Figure 5 Research Flow

Further to validate the complete working in a professional manner, systematic nomenclatures are designed as shown in Table 5 [3] for better understanding.

Table 5 Research Nomenclatures

Description	Symbols
100% (Fresh Aggregate)	F
75% (Fresh Aggregate) & 25% RAP	F+25%R
50% (Fresh Aggregate) & 50% RAP	F+50%R
25% (Fresh Aggregate) & 75% RAP	F+75%R
100% RAP	R
75% (Fresh Aggregate) & 25% CW	F+25%CW
50% (Fresh Aggregate) & 50% CW	F+50%CW
25% (Fresh Aggregate) & 75% CW	F+75%CW
100% CW	CW
75% Fresh Aggregate + 12.5% RAP + 12.5% CW	F+25%RC
50% Fresh Aggregate + 25% RAP + 25% CW	F+50%RC
25% Fresh Aggregate + 37.5 % RAP + 37.5% CW	F+75%RC
50% RAP + 50% CW	RC

3.0 RESULTS AND DISCUSSION

3.1 Preliminary Findings for Aggregates

Standard laboratory investigations are carried out on the generated samples as discussed earlier. The prescribed findings are related to LOS Angeles Abrasion Testing, Percentage of Fractured particles, Impact Value Test, Flakiness Index, Elongation Index, Specific Gravity, Water Absorption and Soundness Test. The testing procedures are furnished keeping into the consideration of standard guidelines [13]. Complete summary of respective results are presented in Table 6 [3].

Table 6 Initial Findings for Aggregates

Sample / Laboratory Investigation	Los Angeles Abrasion Test ASTM C 131	Percentage of Fractured Particles ASTM D5821-13	Impact Value Test ASTM D5874	Flakiness Index ASTM D 4791	Elongation Index ASTM D 4791	Specific Gravity and Water Absorption Test ASTM C127-12		Soundness Test, Sodium Sulphate (Na2 So4) ASTM C88
						Specific Gravity	Water Absorption	
Standard Specification	30%	30%	30%	15%	15%	3	2%	12%
F	12.58%	21.06%	8.23%	9.32%	10.47%	2.62	0.20%	5.68%
F+25%R	14.28%	26.20%	8.87%	9.58%	10.90%	2.85	0.16%	5.44%
F+50%R	17.38%	29.44%	12.55%	10.72%	15.07%	2.90	0.16%	4.84%
F+75%R	20.64%	32.92%	14.62%	11.18%	18.63%	3.14	0.10%	4.18%
R	21.88%	36.27%	18.28%	12.93%	19.00%	3.39	0.09%	3.28%
F+25%CW	16.92%	30.18%	15.01%	10.43%	12.15%	2.94	0.35%	8.24%
F+50%CW	30.28%	36.97%	28.34%	16.29%	21.28%	3.02	0.69%	10.08%
F+75%CW	34.44%	41.97%	32.64%	26.53%	26.88%	3.27	0.88%	14.72%
CW	50.38%	49.61%	39.34%	27.12%	27.17%	3.37	1.20%	22.52%
F+25%RC	15.76%	29.90%	13.00%	12.13%	14.35%	2.82	0.36%	6.24%
F+50%RC	22.92%	36.15%	18.54%	12.88%	16.10%	3.02	0.69%	8.58%
F+75%RC	30.28%	41.20%	24.09%	17.42%	17.87%	3.26	0.77%	13.28%
RC	38.52%	48.92%	32.19%	28.09%	13.92%	3.22	0.83%	17.84%

The combination for the aggregates are revealed specifically for fresh aggregates, RAP, CW and RAP+CW while the ranges are attained within 25%, 50%, 75% and 100%. In addition to the listed tests, sieve analysis is also conducted which shows the equivalent percentages of RAP and CW to the percentages of fresh aggregates and cumulative percentage passing [14]. The output results are in lines with the standards for all sets of combinations. The concept of particle size distribution is governed in such cases followed by the toughness measures and angularity indices of aggregates. This choice of method is interrelated with orientation of different sieve sizes in accordance with the set out standards and sample assignments.

Similarly, with the increase in RAP material in abrasion test, the subsequent values are resulted due to the high percentage of finer particles. In other words, all processed samples are observed as within the permissible limits [15]. As far as the case of crushing is concerned, exceeding limits are obtained due to the variety in waste materials which is due to the retrieve of samples from pre-loaded structures. Another important parameter is the accountability of soundness test [16]. This test implies the monitoring of resistance for weathering actions. An increasing rate of soundness is observed for 100% fresh aggregates. The relevant causes for this evaluation may be frictional forces deprived from vehicles and variations in existing construction works.

3.2 Preliminary Findings for Bitumen and Grouting Material

Complete bitumen and grouting material characteristics are represented in Table 7 [3] and Table 8 respectively. Standard evaluations like penetration, viscosity, density, consistency and setting times are considered in this domain. For having particular bitumen grade, it is considered as adequate and sustainable to all derived conditions and followed arrangements.

Table 7 Results for Bitumen

Bitumen Grade	Penetration (dmm) ASTM D5/D5M	Softening Point (°C) ASTM D36/D36M	Viscosity (Pa.s) ASTM D21710	Density (g/cc) ASTM D70
80/100	83.2	46.2	0.067	1.0321

Table 8 Initial Results for Grouting Material

Ordinary Portland Cement (OPC)	Consistency (Water) gm/ml ASTM C187	Initial / Final Setting Time (minutes) ASTM C191	Soundness ASTM C151	Specific Gravity ASTM C188
ACPL Falcon Cement	30%	46 / 198 (min)	2.5	3.15

3.3 Experimental Analysis for Achieved Blend Grading

For having achieved blend grading in open graded asphalt skeleton, analysis is perceived separately for RAP, CW and combination of RAP+CW in addition to fresh aggregates [17]. In all the combinations, the percentage of fresh aggregates is accordingly decreasing with the increase in the percentage of RAP material. The respective arrangements are shown in Figure 6, Figure 7(a & b) and Figure 8 [3].

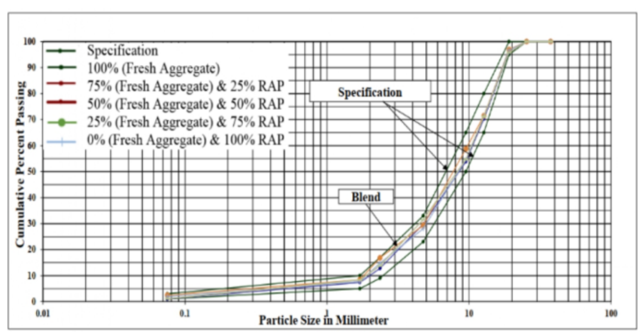
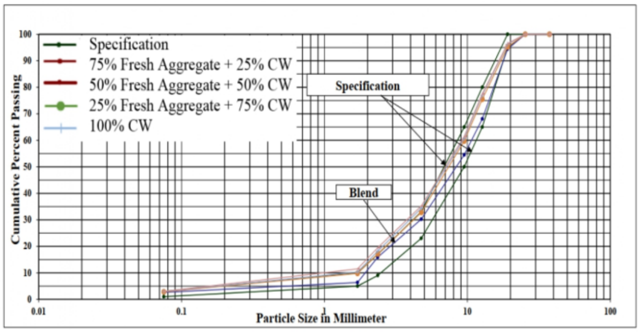


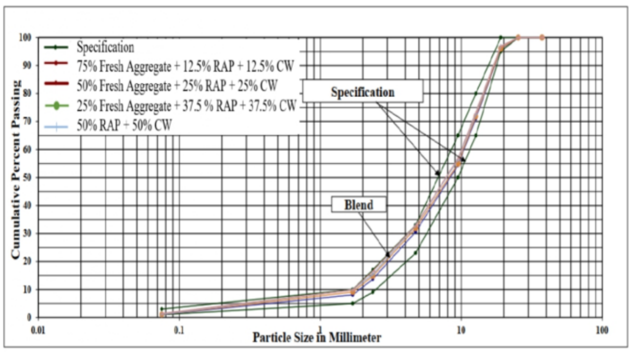
Figure 6 Blend Grading (Fresh Aggregates and RAP)

The blend grading is customized with the specifications using the standards AASHTO T 30. Significant values are obtained for the increasing percentages of RAP material however more prominent results may be depicted in 100% RAP with

0% involvement of fresh aggregates [18]. The particular reason behind these observations is the variation in the distribution of particle sizes opted from reclaimed material.



(a)



(b)

Figure 7 Blend Grading (a) Fresh Aggregates and CW; (b) Fresh Aggregates and RAP+CW

3.4 Design of Semi-Rigid Mix

An empirical analysis is presented in Table 9 for the design of semi-rigid mix on account of several discussed combinations [19]. The combinations are pertained to the recommended air voids in support to the calculations of average stability at Optimum Bitumen Content (OBC) [20]. These calculations are presented for grouted and without grouted samples. It is clearly observed from the analysis that stabilities are interdependent to two major entities which are bitumen contents and curing days [21]. Nevertheless, to maintain air voids in the process is another essential parameter. This perspective design approach is also elaborated in Figure 8. It is quite evident that average stability is checked at 4% controlled air voids in consideration to the set out standards [22]. The representative samples are being processed against controlled air voids, ungrouted and further on grouted samples. Low stabilities are achieved at controlled air voids due to the presence of construction waste however majority ungrouted samples are not fulfilling the certain criteria of ESALS due to sudden failiures. Infact, grouted samples have got enhanced stabilities with respect to the particular choice of the curing days. The stability in this case is governed by the percentage of air voids followed by the filling of grouting material in semi-rigid mix. There is a directly proportional relationship between the percentage air voids and amount of grouting material required leading to the lesser amount of rutting along with increased stability and viceversa.

Table 9 Design Approach

Design of Semi Rigid Mix											
Sample Combinations		Maintained Air Voids (VTM %)	Average Stability at Controlled Air Voids (4%)	Average Stability (kgf) without Grouted Samples	Weight of Cement (OPC) in gm	Weight of Sand gm	Total Weight of Sample gm	Average Stability (kgf) Grouted Sample			
								at 3 Days Curing	at 5 Days Curing	at 7 Days Curing	at 28 Days Curing
	A1	25.36%		916.27	172.45	172.45	1544.90	4137.19	4650.20	4812.96	5053.61
F	A2	30.29%	1446.57	613.90	205.97	205.97	1611.94	4585.63	5163.42	5307.99	5679.55
	A3	35.61%		386.76	242.15	242.15	1684.30	5308.91	6030.92	6193.76	6751.20
	A4	25.76%		826.54	175.17	175.17	1550.34	3002.99	3390.37	3515.82	3691.61
F+25%R	A5	30.33%	1028.42	504.19	206.24	206.24	1612.49	3260.09	3680.64	3816.83	4084.00
	A6	35.58%		347.89	241.94	241.94	1683.89	3774.30	4261.19	4542.42	4651.44
	A7	25.85%		668.27	175.78	175.78	1551.56	2569.40	2903.42	2981.81	3458.90
F+50%R	A8	31.80%	868.04	447.74	216.24	216.24	1632.48	2751.69	3109.41	3218.24	3420.98
	A9	35.80%		331.33	243.44	243.44	1686.88	3185.71	3599.85	3725.84	3845.07
	A10	25.92%		550.86	176.26	176.26	1552.51	2248.71	2675.96	2769.62	2825.01
F+75%R	A11	30.82%	754.6	484.76	209.58	209.58	1619.15	2392.08	2846.58	2946.21	3067.00
	A12	36.08%		319.94	245.34	245.34	1690.69	2769.38	3295.56	3549.32	3716.14
	A13	26.06%		508.36	177.21	177.21	1554.42	2061.97	2618.70	2710.36	2797.09
R	A14	30.94%	685.04	305.02	210.39	210.39	1620.78	2171.58	2757.90	2854.43	2948.63
	A15	36.20%		207.41	246.16	246.16	1692.32	2514.10	3192.90	3365.32	3614.35
	B1	25.14%		648.84	170.95	170.95	1541.90	2738.47	3110.90	3191.78	3498.19
F+25%CW	B2	30.59%	954.17	356.86	208.01	208.01	1616.02	3024.72	3436.08	3597.58	3716.30
	B3	36.10%		192.70	245.48	245.48	1690.96	3501.80	3978.05	4272.42	5425.98
	B4	26.21%		394.77	178.23	178.23	1556.46	2152.59	2437.03	2670.99	2819.23
F+50%CW	B5	30.21%	744.84	236.86	205.43	205.43	1610.86	2361.14	2673.14	2903.03	3039.48
	B6	35.65%		156.33	242.42	242.42	1684.84	2733.56	3094.78	3178.33	3273.68
	B7	25.26%		460.75	171.77	171.77	1543.54	2046.26	2300.00	2355.20	2442.34
F+75%CW	B8	30.06%	677.57	290.27	204.41	204.41	1608.82	2147.90	2414.24	2467.35	2625.26
	B9	35.17%		179.97	239.16	239.16	1678.31	2486.68	2795.03	2892.86	3170.57
	B10	24.88%		334.41	169.18	169.18	1538.37	1478.18	1661.48	1719.63	1800.45
CW	B11	29.54%	484.65	224.05	200.87	200.87	1601.74	1536.34	1726.85	1787.29	1842.69
	B12	34.90%		194.93	237.32	237.32	1674.64	1778.67	1999.22	2069.19	2095.06
	C1	25.95%		756.67	176.46	176.46	1552.92	3082.26	4204.20	4595.19	5017.95
F+25%RC	C2	29.24%	991.08	454.00	198.83	198.83	1597.66	3141.72	4285.31	4503.86	4747.07
	C3	34.76%		304.18	236.37	236.37	1672.74	3637.26	4961.23	5244.02	5438.05
	C4	25.70%		573.65	174.76	174.76	1549.52	2624.44	3428.83	3771.71	4050.82
F+50%RC	C5	29.39%	843.6	372.87	199.85	199.85	1599.70	2674.21	3493.86	3913.12	4085.30
	C6	34.90%		261.01	237.32	237.32	1674.64	3096.01	4044.94	4186.51	4450.26
	C7	25.17%		502.80	171.16	171.16	1542.31	2260.84	3061.18	3348.93	3405.86
F+75%RC	C8	29.88%	728.7	372.07	203.18	203.18	1606.37	2309.98	3127.71	3416.71	3519.21
	C9	34.44%		260.45	234.19	234.19	1668.38	2674.33	3621.04	3747.78	4028.86
	C10	25.01%		404.88	170.07	170.07	1540.14	1917.40	2435.09	2549.54	2766.26
RC	C11	29.91%	586.36	263.17	203.39	203.39	1606.78	1970.17	2502.12	2644.74	2761.10
	C12	35.33%		223.70	240.24	240.24	1680.49	2151.94	2732.97	2802.66	3057.70

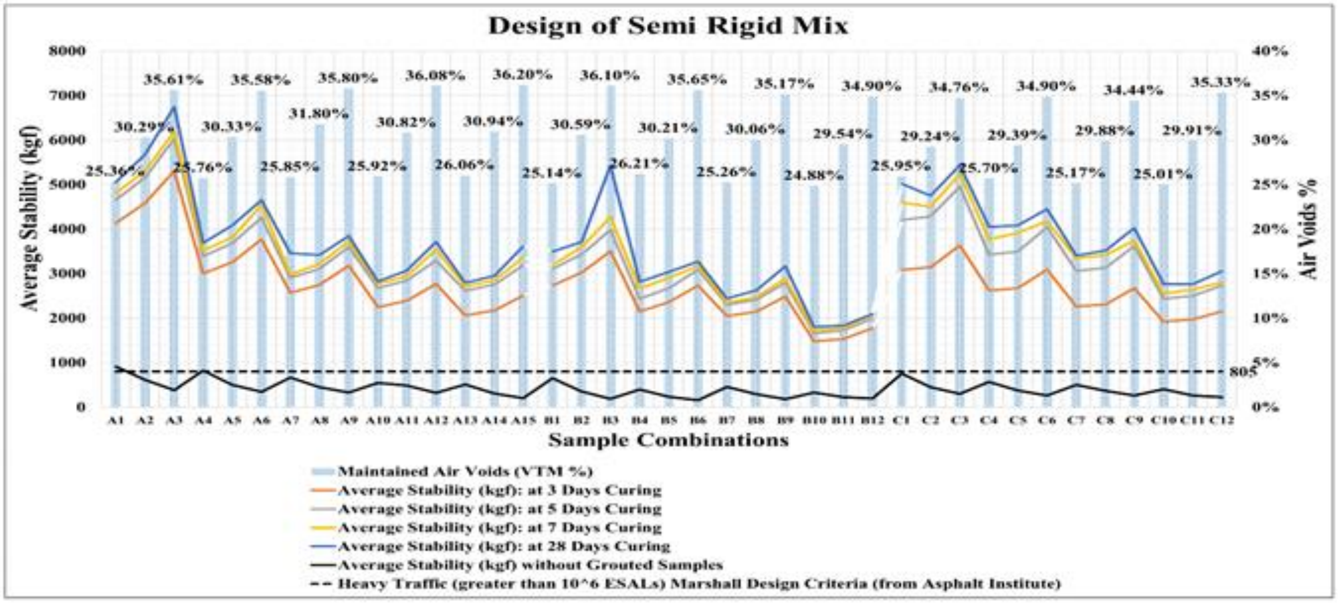


Figure 8 Graphical Illustration (Design of Semi-Rigid Mix)

Despite of that, all samples may be correlated and ranked in lieu of the average stabilities marginalizing the standard requirements of ESALS. The number of ESALS are further dependent on the expected truck loads accordingly. Not only that, the relationship between avergae stability of grouted samples and timeliness of permitted traffic may be developed through the specified days of curing for example 3 days, 5 days, 7 days and 28 days. Amount of grouting material and curing days are two formal important and significant parameters in the design of semi-rigid mix.

3.5 Rut Depth Measurements

This particular research is associated with the measurements of rut depths for semi-rigid mix accompanied with the recycled materials. The novelty of this research is basically the measurements of rut depths. These rut depths are checked against grouted samples of semi-rigid pavement to obscure the design adequacy [23]. Rutting action on the pavement is monitored through advanced implication of the use of wheel tracker device in which artificial wheel passes are generated on the samples and results are accumulated in terms of rut depths. To measure the feature of rut depth is actually the observance of the resistance against rutting. Roads which are accompanied with alligator cracks and potholes are usually resulted into the rutting distress [24]. Rutting is taken as the severe road distress in distress indices. Under normal circumstances, it is pre-examined through the checks of rut depths on prescribed samples [2].

As discussed above, the research is pre-determined for rut depths of grouted samples maintaining 25%, 30% and 35% air voids in considerations to the subjected combinations [25]. As analyzed earlier, the combinations are arranged in lieu of fresh aggregates, RAP, CW and RAP+CW. Perhaps, all are being subsidized in the analysis for identified air voids. The complete trends are represented in Figure 9, Figure 10 and Figure 11. The experimentations revealed that due to the increase in the percentage of air voids in respective samples, more grouting material is incorporated and for the same; samples have come across with the acceptable limits of rut depths. This is also dependent on the choice of the reclaimed materials and their allied properties [6]. Hence, it is determined that the calculated involvement of grouting material keeping in view of air voids and use of indigenous reclaimed materials in semi-rigid pavement may enhance its characteristics properties for improved pavement life [15].

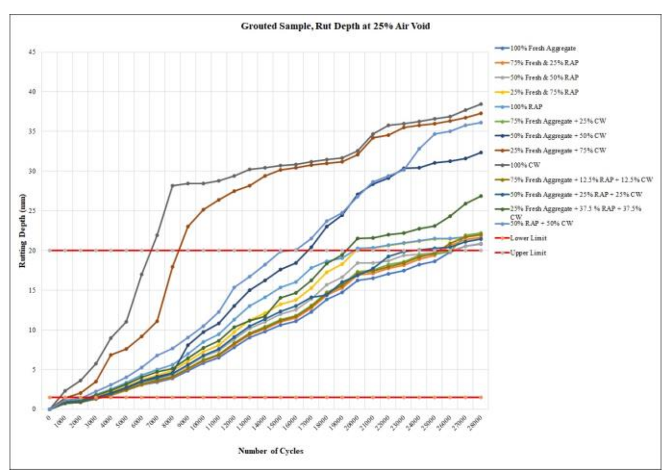


Figure 9 Trend Line Analysis (25% Air Voids)

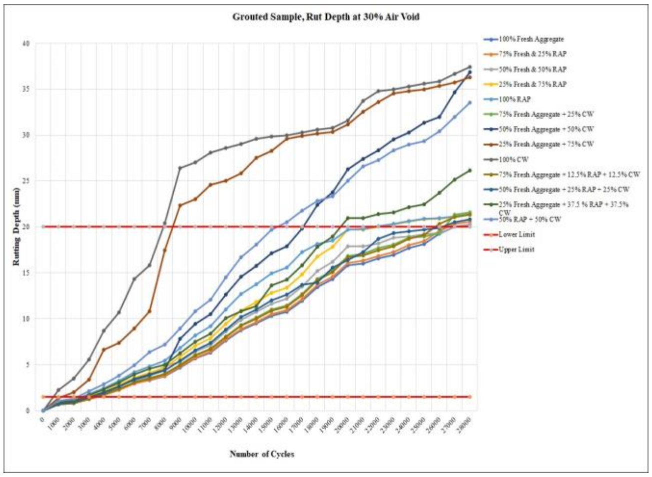


Figure 10 Trend Line Analysis (30% Air Voids)

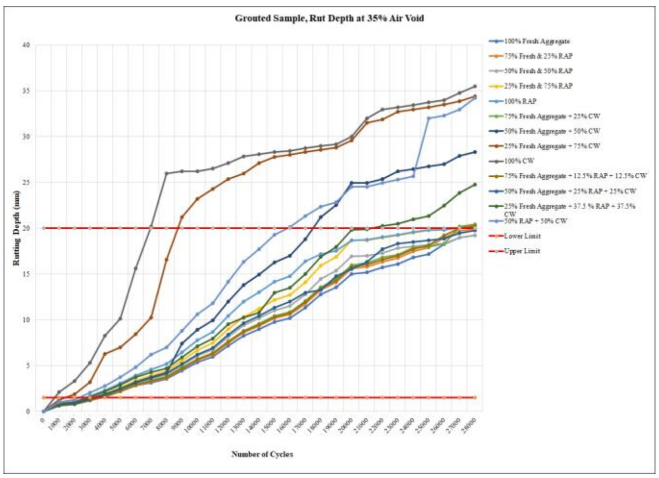


Figure 11 Trend Line Analysis (35% Air Voids)

4.0 CONCLUSION

The overall research is entitled with the behavior of semi-rigid pavement in support to its use with recycled materials. The research itself has got several directions to which stakeholders may take benefits accordingly. One of the intellectual step that may contribute is the improved durability of the mix which is to be generated from the waste materials. It is also quite evident that the RAP and CW material is normally disposed and hence it is being constituted for an efficient, economic and durable mix design. The research itself is providing the solutions for infrastructrure industry in terms to promote the semi-rigid pavement constituted with recycled materials. For instance, this study is giving a brief idea about the standard experimentations or mainly the base tests for preliminary required materials. The materials include aggregates, bitumen and grouting material. The analysis is extensively addressed in terms of aggregates by representing its different combinations with fresh aggregates, RAP and CW. Somehow the blend combinations of RAP+CW are also distinguished. In the same way, the experimentations are extended for achieved blend grading with respect to all possible stated combinations. On the contrary, these steps were pre-required for the initiation to inculcate design of semi-rigid mix. Complete procedure is defined in the research in connection to all the parameters of respective mix design. The essential elements including maintained air voids, average stabilities for controlled air voids, without grouted samples and grouted samples considering different days of curing are carefully assessed in order to present a deterministic model for the practitioners. The research is synchronized in a way to cater the rutting behavior for particular type of pavement by generating the rut depths on subsequent percentages of air voids using advanced equipment. Representation of rut depths at certain levels focusing different combinations of aggregates is an active and integral part of the research in various ways. Apart from that, the research is viable to develop a conceptual model for semi-rigid pavement featuring the perpetual benefits from the existing construction resources and sound customization within the samples. The interesting features of the research is the capability of the grouting material in the air voids and further the monitoring of improved properties. Above all, this research covers the broader perspective to accumulate the resources of RAP and CW on technical note within the controlled features in order to ascertain the economic challenges of the country. The research analysis clearly signifies the cost control of fresh aggregates with the use of 100% RAP material focusing the established model. Similarly, this also ascertains to minimize several other expenses like transportation and dumping costs. The research itself is giving a brief idea to replace fresh aggregates along with recycled materials. In this connection, interpretations are idealized for optimum bitumen content in accordance with the combination of aggregates and recycled materials. The specific analysis resembles the comparison between grouted and ungrouted samples considering the design of semi-rigid mix. Interesting results show that using 100% RAP and 50% RAP + 50% CW achieves maximum stability of 3614 kgf and 3057 kgf, respectively, after 28 days of curing. Apart from that, significant results may also be obtained after 3 and 5 days of curing. It is also stated by the researchers that recycled materials are widely available, but it is crucial to select the most suitable materials for semi-rigid mix through specific mechanisms, standard experimentation, and critical analysis. In addition to that, the escalation cost of fresh aggregates has also increased by 20% (approximately) within the year, according to current market rates, which is a matter of concern for relevant stakeholders.

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Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper.

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