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Parametric characterization of semi-rigid asphalt skeleton using recycled materials

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ABSTRACT

Concrete Pavement with significantly good resistance to wear and tear is expensive while asphalt pavement can easily be constructed and repaired but is not durable. In considerations to cost-benefit, modification in pavement construction plays a vibrant role. Exploration in semi-rigid pavement construction is getting common. This paper signifies the viable solutions of similar pavement using recycled materials. The methodology is based on detailed analysis of laboratory experimentations within the combinations of fresh aggregates, Reclaimed Asphalt Pavement (RAP) and Construction waste (CW). Focusing blend grading, clear differences are obtained between the stabilities of grouted and un-grouted samples. Likewise in the case of 100% RAP with minimum air voids and curing time, about 300% increase in stability observed in grouted sample. The paper corresponds to save the cost of 100% fresh aggregates identifying the need of the research. Possible combinations of RAP and CW reveal the passing of certain limits through grouting.

1. Introduction

It is important to visualize the conceptual framework for such type of study in which novelistic materials are used within the construction of semi-rigid pavement [1]. In order to mitigate the issues of semi-rigid pavement with the use of recycled materials, it is required to create a standard mechanism for preliminary investigations that must be helpful to interpret against the design mix of semi-rigid pavement in similar fashion [2]. The suitability of material in individual type of pavement should be in accordance with the standard specifications however it must be in lines with the availability and economical perspective of subject pavement material. In the long run, this research study might be taken as an initial review to check the characteristic parameters of semi-rigid pavement samples with its smart modifications and emerging grouting materials. The thematic idea is governed on the use of domestic recycled materials rather than fresh base material. In addition to that, they have come across for required testing in Ordinary Portland Cement (OPC) as grouting material [3]. The arrangements are further checked with bitumen grade of 80/100 accordingly. The perspective outcome which may be defined for stakeholders from this study is the deterministic evaluations of semi-rigid pavement focusing key experimentations and findings for optimal ranges. Not only that, but the research also promotes the usability of recycled materials in semi-rigid pavement with a great focus to interpret economical bindings of infrastructure. The mechanism may be justified in three broad categories which are laboratory investigations, design of conventional hot mix asphalt and design of semi-rigid mix [4]. The observed assessments through particular mix design procedure may be further utilized to channelize the framework for source materials of semi-rigid pavement [5]. These may include type of material and devise mechanism as an intellectual step towards the use of recycled materials. The findings carried out during this research may be influenced with the use of recycled materials. The research is providing a mechanism to use recycled materials in an appropriate fashion to the consultant. Despite of that, the fluctuations in the cost for respective model may create discrepancies for a network of practitioners. Focusing with the solutions to the target problem the research is given an economical and novel approach to relevant group of stakeholders.

2. Deterministic Approaches in Pavement Infrastructures

In Industrial sector, construction is governed with the growth of economy and development. Construction of infrastructure and pavement structures has its own strategy keeping in view the considerations of readily available material that will be used during the process [6]. The workability of any infrastructure project is dependent on the selection and suitability of materials in connection to civil structures, its affectivity and sustainability. This may ensure the credibility of pavement mix with or without the use of recycled materials [7]. Similar analysis is carried out for the research in later sections. By looking towards the traffic situation and HTV's requirements, certain workable structures are in practice in urban and rural areas. In this connection, selection of pavement material for respective construction is also affected by traffic flow analysis of observed area [8]. Three basic types including Rigid, Flexible and Semi-rigid pavements are utilized for such constructions. These types have their own characteristic properties to smart use inclusive of bond mechanism with asphalt, concrete and primarily aggregate macadam [9]. In context to the major findings for pavement construction, conceptual approach for composite pavement is more common. It is categorized into two cases; case-I: flexible over rigid layer and case-II: rigid pavement over existing bituminous pavements. Case I is normally jointed plane concrete pavement or continuous reinforced concrete pavement. In this approach, flexible layer is placed in order to enhance the performance of rigid layer. This layer reflects the action of thermal and moisture blanket reducing vertical temperature moisture gradient. For case II, the thickness requirements are 200mm for conventional white topping surface layers and 100 to 200mm thickness for thin white topping on top of flexible pavement [10].

Another area is the advancements in Cement-treated layers. The idea is more applicable as its availability in road base. Collectively, it is composed of particular type of aggregates with variations in the percentage of cement and water considering adopted technique [11]. Normally Portland cement is used for such purposes. Sometimes it is also proposed with the involvement of lean concrete and cement bound granular materials, but the mix design is dependent on the efficiency of batching plant according to its strength and uniformity modes [12]. It is quite evident that the characteristics of mix design is also affected by the adopted design approach and suitability of aggregates material. In the same way, grouted semi-flexible pavement (GSP) is a novel approach comprising of open graded asphalt concrete followed by the grouting action of high-fluidity cement mortar [13]. Because of significant load bearing capacity and anti-rutting performance, it may be influenced as anti-rutting overlay in road constructions [14].

3. Semi-Rigid Pavement Construction and its Applicability with Recycled Materials

Semi-rigid pavements are derived to predict the performance of stabilized layers. Normally a rigid pavement is designed to create a dispersed pressure in subsequent layers however flexible pavements are more oriented towards loaded area [15]. Thus, in the presence of cemented layer as accumulated with subgrade of flexible pavement, the pressure may be more dispersed with a new arrangement termed as semi-rigid pavement. Semi-Rigid Pavement comprises of Bitumen, aggregates and porous mix with the presence of 25% to 30% air voids [16]. These voids are processed with some suitable grouting materials. The structural features of this type of pavement is varied when compare to the behavior of individual Rigid or Flexible pavements that is why the subject type of pavement is more prevalent to its efficient use [17]. The constraints, limitations and comparison of semi-rigid pavements with other types are evaluated focusing experimental considerations and respective overcome. The overall affectivity for such construction is based on quality of layer resting on subgrade in addition to grouting mechanism [18]. It is a key feature to produce a section of semi-rigid pavement ensuring the effective use of material and adoption of standard procedure to develop a practical and economical infrastructure. The design considerations for this type of pavement are entirely dependent on several factors including structural model for fatigue life, resilient modulus, material properties, traffic intensity, layer performance, thickness curves, involvement of possible additives, reliability and sensitivity with the implications of suitable software’s [19]. Semi-rigid pavements has got the potential of economic savings as well which further may be enhanced with the efficient use of available recycled materials [20].

Rigid and flexible pavements are always concerned with compressive strength and durability respectively while semi-rigid pavement is actually the composite based structure with distinguished properties. These properties may be enhanced more efficiently when it is used with recycled materials [21]. Semi-rigid pavement with the use of recycled materials is always exhibited with numerous factors to other types like conventional construction, asphalt pavements with treated bases and ordinary semi-rigid pavement construction [22]. To develop the understanding of most optimistic solution for pavement construction, it is further required to evaluate all necessary parameters of subject type of pavement. On particular note of analysis, it should be validated with the stringent comparative analysis in different types of pavements. The parameters for comparison may be interlinked in different directions fulfilling all necessary norms of pavement. The pavement parameters must also be checked against economic constraints in order to satisfy stakeholder requirements when an emerging and innovative material is introduced to accommodate [23]. After satisfying all strength parameters of particular type of pavement on standard guidelines, the proposed solution must be cost-effective and its ease in availability by all means. According to the standards, the checked parameters that will ultimately decide the significant use of this type of pavement may be construction cost incurred, transverse load accepted, flexural strength quality, compression and binding domains, load bearing performance index and fatigue property [24].

4. Experimental Contributions Towards Recycled Materials in Semi-Rigid Pavement

Variety of recycled materials are available in construction industry to be incorporated in pavements. The particular use must ensure the credibility and nature of construction works in addition to the use of pavement materials. According to a research, satisfaction levels of alternatives materials are attained that may be utilized as replacement of aggregates, binding materials and grouting agents [25]. The matrix is achieved by categorizing the satisfactory, conditionally satisfactory and not satisfactory levels however the studied materials incorporated are reclaimed asphalt, crushed concrete, foundry slag, crumb rubber, ash, glass and plastics. Blast furnace slag is also recommended as the second reusable material for highway pavement construction focusing its use as a supplementary material for increased sustainability in concrete pavements [26]. Recycled glass is another source in glass production technology. Rice husk and fly ash are more common to be taken into account in semi-rigid pavements. Rice husk is also utilized in reclaimed asphalt pavement in consideration to stabilization. The use of this material with reclaimed asphalt has similar benefits in terms of reduction of amount of waste and provision of construction materials with significant savings [27]. Rice husk ash is normally obtained in bulk from a rice-mill dump however it is normally processed with standard sieves. Rice husk has given more importance in asphalt industry as a kind of filler or additive in order to enhance the properties of asphalt materials. Some studies have shown its combination with crumb rubber powder for the preparation of modified asphalt binder affecting the performance with high temperature [28]. Use of fly ash is also significant in saving number of resources. As a grouting material in pavement, cement is expensive so its arrangement may be made with it without losing the strength which eventually will solve the problem of disposal and construction cost. Similarly, a study is carried out in which cement-lime-fly ash bound macadam is used as a base material [29].

Furthermore, RAP is commonly used as aggregates particularly in recycled asphalt paving however similar practice is also adopted in semi-rigid pavements proficiently as recycled materials. Specifically, it has high binding qualities than virgin asphalt binders therefore this material is kept also into considerations where rehabilitation and maintenance is required within prescribed time [30]. Very few research is available in which comparison is carried out in this domain for virgin and modified asphalt binder in accordance with recycled aggregates and grouting materials. During the processing of RAP, multiple steps are involved to meet quality standards of during mixes. In this connection, screening method is adopted to further control and separation of oversize particles ensuring the required strength with nominal sizes. RAP sizes are also classified as coarse or fine or sometimes oversize, coarse or fine depending upon the scale. For accuracy, fractionation equipment is utilized in which crushing and screening is done simultaneously [31].

5. Scientific Analysis and Research Framework

Marshall Mix design is being approached to interpret the findings of the experimentations. Similar areas are also accounted to specify the volumetric properties however considerations are given to maintain of air voids as prescribed. The baseline for all the methods are same while the design process is based on certain steps including aggregate selection, asphalt binder selection, sample preparation, performance testing, density and voids calculations, optimum asphalt binder content selection and moisture susceptibility evaluation [32]. The selection of aggregates may be dependent on the angularity of the particles and its combination with the source material in terms of asphalt. The parameters that need to countercheck in mix design method are stiffness, stability, durability, permeability, workability, fatigue resistance, frictional resistance and resistance to moisture damage. As per the guidelines, 4% air voids are recommended in flexible pavements against the assessments of bitumen content while this percentage will be distinguished as 25%, 30% and 35% for semi-rigid pavements [33]. Air voids in semi-rigid pavement are specifically meant for grouting action. The scientific experimentations and analysis carried out is to bring the connection of all parametric properties of basic constituents of semi-rigid pavement asphalt skeleton within the involvement of recycled materials. For the same, the study shall ensure about the detailed investigations on characteristics of pavement focusing fresh and recycled aggregates in lines with its appropriate combinations. In addition to that, the understanding of blending mechanism shall be developed against said type of pavement focusing bitumen content and comparison for average stability. The average stability is accounted in experimentations for with and without grouted samples. Similarly, the used bitumen grade for specific samples must be in accordance with the uniform volumetric properties.

The methodology of the research is idealized in a manner to broadly cover the overall testing procedures. As identified in Fig. 1 below, initial investigations are carried out in terms of aggregates, bitumen and grouting material. Recycled aggregates are categorized in suitable percentages of RAP and construction waste along with the provision of fresh aggregates. In the same way, design of conventional mix is derived against opted category of bitumen while 25%, 30% and 35% air voids are maintained in order to check average stability at certain stages. The average stability is being checked for grouted and un-grouted samples however grouted samples are comparatively analyzed against 3 days, 5 days, 7 days and 28 days curing. As far as material description and location of samples are concerned, sources of fresh aggregates and OPC are Sindh stone crusher Nooriabad and Attock cement Pakistan limited, Falcon cement respectively. Grade 80/100 bitumen is used and generated from National refinery limited, Korangi Industrial Area, Karachi. RAP material and construction wastes are derived from specific locations including Shahrah-e-Pakistan near toll plaza, Karachi, Link Road, Education city, Karachi, Shahrah-e-Faisal near Awami Markaz, Aladin park and Nasla tower, Karachi. The main purpose for the selection of these locations is the availability of complete material and documentation for accounted samples. The regenerated sample are checked and monitored in conditioned to the standard guidelines and specifications. In addition to that, the history of the locations also reflects with the proper design and construction phases accordingly. The applicability of grade 80/100 bitumen is due to the provision of consistency in specified samples [34]. Apart from that, particular type of bitumen is also addressed due to the key control in volumetric properties.

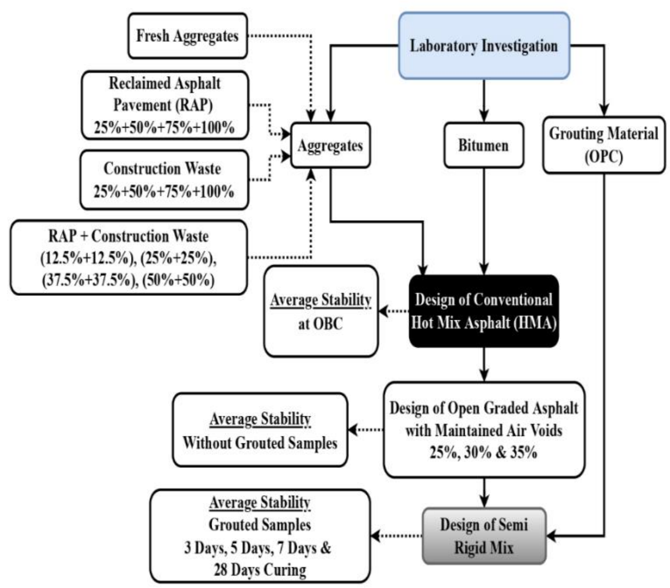

Fig. 1. Research methodology

In order to better understand the used combinations and providing the ease in the research, nomenclatures are pre-defined below in Table 1. The assigned nomenclatures are further utilized in all sets accordingly.

Table 1

Pre-defined Nomenclatures

Nomenclature	
Description	Symbols
Fresh Aggregate (FA)	F
Reclaimed Asphalt Pavement (RAP)	R

Construction Waste (CW)	C
100% FA	F
75% FA + 25% RAP	F+25%R
50% FA + 50% RAP	F+50%R
25% FA + 75% RAP	F+75%R
100% RAP	R
75% FA + 12.5% RAP + 12.5% CW	F+25%RC
50% FA + 25% RAP + 25% CW	F+50%RC
25% FA + 37.5 % RAP + 37.5% CW	F+75%RC
50% RAP + 50% CW	RC

6. Mechanical Properties of Base Materials

The experimentations and findings of the research are more pertinent towards the quantification of listed features of pavement using standard approaches. The physical and mechanical tests are employed on samples keeping in mind of standard operation procedures however they are to be checked and verified with the recommended specifications. As discussed earlier, all samples are analyzed within the combinations as fresh aggregates, RAP, CW and RAP + CW. The combinations attained are in the ranges of 25%, 50%, 75% and 100%. The required procedures include sieve analysis, LA abrasion test, crushing test, impact value test, soundness test, specific gravity, water absorption test, flakiness and elongation test, bitumen extraction test and basic findings for bitumen grade and OPC.

In continuation with the base tests, sieve analysis is performed in accordance with the guidelines of ASTM C 136. 5000gms sample weight is kept into considerations while percentage retained is enumerated at 0.75 inches followed by 1 inch for percentage passing. Sample results are enumerated for various arrangements of fresh aggregates, RAP material and CW. It is to be identified that equal percentages of RAP and CW are adjusted in connection to the percentages of FA to build the relationship of cumulative percentage passing.

Under normal circumstances, particle size distribution generally affects the wide range of properties including strength, solubility and surface area [12]. As per the extended analysis, percentage passing was 100% for up to 37.5mm sieve, when fresh and combinations of fresh and RAP were investigated. The computed results are in lines with the standards for different sets of combinations. This option is validated when recycled material is used as discussed in literature of the research. It is observed that particle size is varied in accordance with the toughness, submerged density and angularity of the aggregates.

6.1 LA Abrasion Test, Crushing and Impact Value Tests

The findings are revealed for LA abrasion test as per the standard ASTM C 131. LOS Angeles Abrasion Testing is carried out to visualize the measure of aggregate abrasion, toughness, degradation, and disintegration. These properties are being considered as one of the important parts in order to monitor the bond strength between the assembly. Cumulative results are shown in Fig. 2 below.

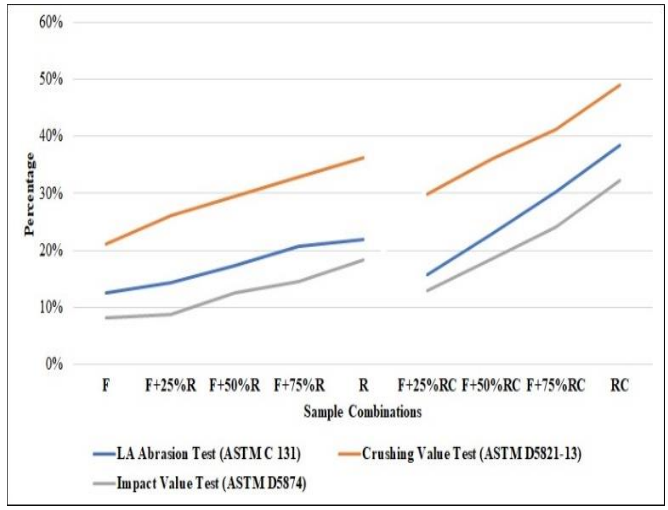

Fig. 2. LA Abrasion, Crushing and Impact Value Tests

While comparing the permissible limit i.e. 30%, Abrasion value is enumerated within the range for the combinations of fresh aggregates, RAP and CW. Gradually, RAP amount is increased within the sample along with lesser amount of fresh aggregates to check the viability of recycled material. Later, with the increase in percentage of such material for 75% and 100%, critical values are obtained considering the permissible limit. The main reason behind this is the reflection of higher percentage of finer particles in the samples resulting into lesser frictional forces between them. From the testing of material from different sources and combination (0% Fresh Aggregates + 100% RAP), the Abrasion value is found to be about 22% followed by the allowable limit which is 30%. It may be stated that most of the selected combination of sample values are within permissible limits. Therefore, samples are assumed to be durable and in good condition to resist weathering action. In addition to that, due to the presence of charge valves in Abrasion Testing Machine, the fine particles in RAP may easily break which may undergo the limits of Abrasion Test. The weathering agents for abrasion could be rain, wind, snow etc depending on the topography and meteorological conditions of area. This specific condition is also important when subjected to the consideration of choice of mix design as the subject matter is also based on existing climatic and traffic requirements [35]. The results are far beyond the limits due to the increase in CW.

On comparison with the standard limit of crushing value, it is observed that certain percentage of fractured particles is increasing with the increase in the percentage of RAP material. As per the results, 32.92% and 36.27% is achieved for 75% and 100% RAP respectively. Limits may be exceeded for varying nature of waste material and its further combinations due to the applicability of loads on already crushed material. It is quite evident to understand the difference between crystal shapes of aggregates and fractured particles in this context [15]. Usually, crystal shapes are produced by cutting through particular parallel axes and planes. Another significant matter in this context is the degree of deterioration of RAP and CW material which is also explored as the critical review of the literature [28]. In the same way, the trend line generated for impact value test is also presented accordingly. The permissible limit for this test is 30% however it is being checked further with certain different combinations. It is clearly observed that increasing trend is attained while using 25%, 50%, 75% and 100% RAP and similar for the combination of the two i.e.; RAP and CW. Similarly, full assembly of RAP + CW (100%) resembles with the higher impact value. This variation is observed as impact is to be assessed on such samples which are opted from deteriorated materials like crushed stones and Reclaimed material [28].

6.2 Determinations for Flakiness and Elongation Indices

Flakiness and Elongation is checked to undergo with the uniformity of sample. The standard range for the same is 15% and may considerably increase with the increase in the percentage of RAP. Results are kind of similar when presented within the combination of RAP and CW. The experimented critical values for 50%, 75% and 100% RAP against elongation are 15.07%, 18.63% and 19.00% respectively. For similar percentages, results obtained for RAP against flakiness are 10.72%, 11.18% and 13%. Considering the specified combinations of FA, RAP and CW, mixed trend is observed in this analysis as depicted in Fig. 3 below. Under normal circumstances, flaky and elongated particles lower down the workability due to increased ratio of surface area to volume while the degree of packing is variably dependent on their shapes accordingly [36]. Normally variations are observed and accounted in the degree of packing of the samples. This is due to the significant particle size distribution in the observations and analysis.

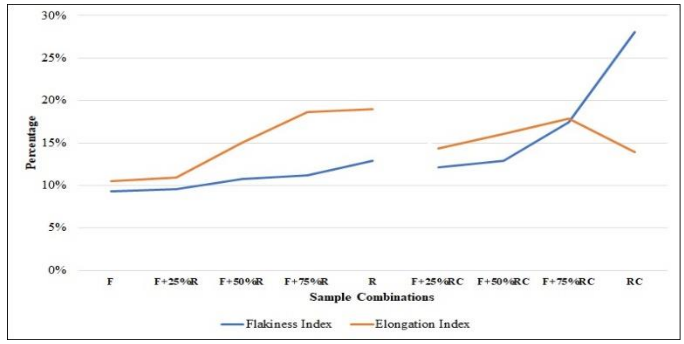

Fig. 3. Measures for Flakiness and Elongation Indices

6.3 Specific Gravity and Water Absorption Test

The findings for specific gravity are mentioned in Fig. 4. Directly proportional relationship is achieving between specific gravity and proportions of RAP while ranges are quite variably defined in the case of combination of FA + RAP + CW. In-fact, nominal range may be accumulated for it if there is a distinct behaviour of RAP and CW material in sample collection. The samples for RAP and CW are carefully monitored for water absorption as the material was come across with the absorption capacity in the existing structures. The standard permissible limits for water absorption and specific gravity are 2% and 3 respectively.

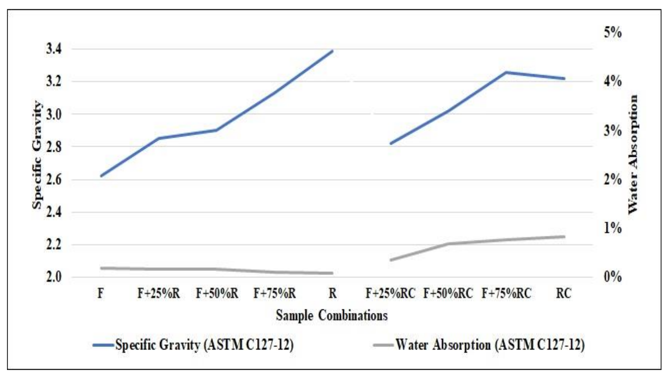

Fig. 4. Measures for Specific Gravity and Water Absorption

It is monitored during said experimentation that with the increase in the proportion of RAP, absorption value is decreased a bit. This is due to the already coated material and closure of pores. In addition to the RAP material, water absorption capacity may be marginally effected on the use of several other types of wastes like CW. The said combinations are the varying percentages of construction waste and RAP in addition to the FA.

6.4 Results for Soundness Test

Soundness test is accompanied to check the resistance against weathering forces. For this test, the standard is set out as 12% (ASTM C 88) while the complete findings are given below in Fig. 5. The chemical utilized in said test is Sodium Sulphate.

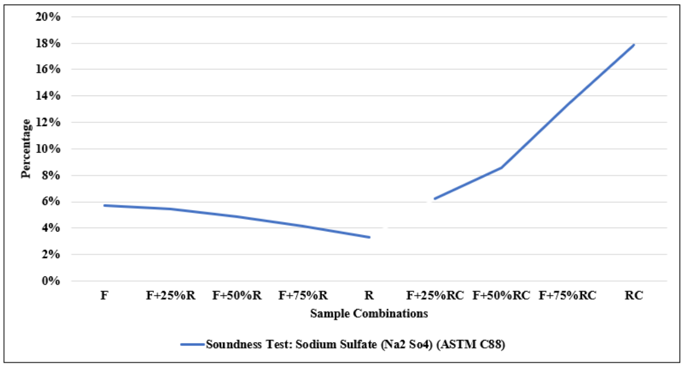

Fig. 5. Observed Trends for Soundness Test

It is investigated that increased percentage of soundness is measured against the case of 100% fresh aggregates. The resulted values for 75% and 100% RAP are 4.18% and 3.28% respectively. Similarly, highest percentage of 17.84% (more than that of maximum permissible limit) is observed against the case of 50% RAP + 50% CW. Considering existing literature, results are being differentiated due to the involvement of number of frictional forces by vehicles and pre-loading of aggregates with respect to the samples generated. Pre-loading could be of any choice depending upon the nature of existing construction works [8].

6.5 Bitumen Extraction Test

Bitumen extraction test is justified with the standard as ASTM D2172. It is used to predict the percentage of bitumen content available in the pavement using cold solvent extraction. The dependent parameters in this domain are durability, compatibility, bleeding, revelling and ageing of pavement. As far as ageing is concerned, both long-term and short-term ageing should be kept into considerations [37]. Complete findings are presented in Fig. 6 below.

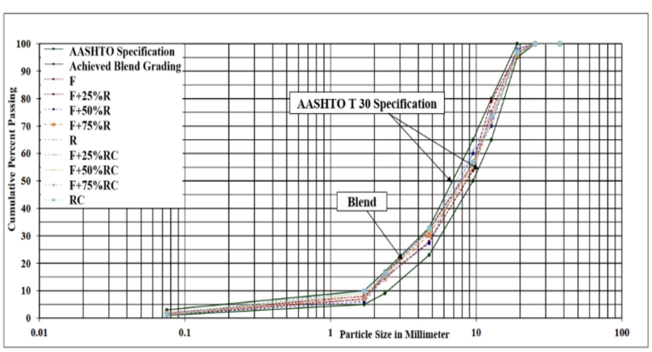

Fig. 6. Determinations for Bitumen Extraction Test

6.6 Characterization for Bitumen Grade

In order to evaluate the characteristics of 80/100 bitumen, basic properties are approached as follows in Table 2. These tests include Penetration, Softening Point, Viscosity and Density. As discussed above that the choice of grade of bitumen is entirely dependent on its volumetric properties and uniform features.

Table 2

Bitumen Characteristics

Bitumen Grade	Penetration (dmm)	Softening Point (°C)	Viscosity (Pa.s)	Density (g/cc)
80/100	83.2	46.2	0.067	1.0321

6.7 Characterization for Grouting Material

The major evaluation is being done for ordinary Portland cement. The results are tabulated below in Table 3.

Table 3

Characteristics of Grouting Material

Ordinary Portland Cement	Consistency (Water) (gm/ml)	Initial/ Final Setting Time (Minutes)	Soundness	Specific Gravity
ACPL Falcon Cement	0.3	46/198	2.5	3.15

7. Design of Hot Mix Asphalt at OBC

This extended part of the analysis is basically based on the use of materials for experimentations in accordance with the sieve sizes and set of hot bins in consideration to particular mix design approach. Hot bins are classified with respect to the percentage of the material. Moreover, it is to be further interpreted for synchronization of optimum bitumen content which is then to be utilized for symmetrical parameters of semi-rigid pavement. Results are presented in terms to address blend grading, OBC and voids in total mix.

7.1 Open Graded Achieved Blend Grading for Hot Mix Asphalt

Fig. 7 below is the detailed and cumulative analysis in conditioned to asphalt mix design. It is representing the sample combinations with varying percentages while they are to be also assessed for the evaluation of bitumen content accordingly. Here, it is obvious that for each particular source, bitumen content is to be carried out individually so as to undergo with the modifications in the overall ingredients while the results may be accordingly varied with respect to the opted source of extraction. This part is essentially required to focus the design considerations in a systematic way.

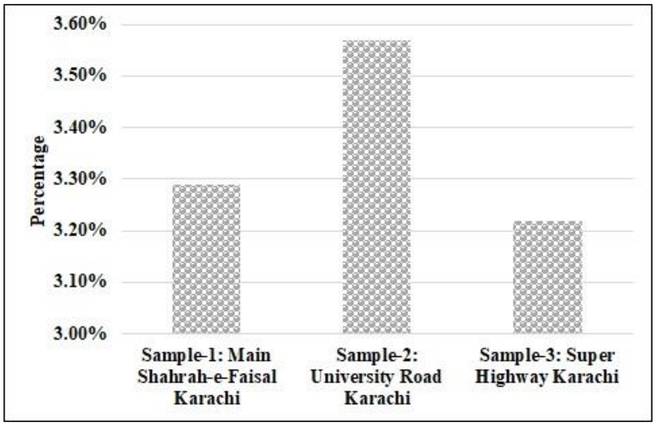

Fig. 7. Graphical Illustration for Particle Size and Cumulative Percentage Passing

The analysis is produced within the set of combination of aggregates in blend grading. The graphical patterns are justified and compared considering the standard specification limits.

7.2 Optimum Bitumen Content and Voids in Total Mix

Samples are prepared with 100% fresh aggregates to 100% RAP in addition to the similar increment of 25% RAP up to 100%. The OBC of fresh aggregates is 3.9% along with the voids 4.16%. It is monitored that with the addition of RAP with Fresh Aggregated there is a gradual decrease in OBC due to the existing coating of bitumen. The area is strengthened in terms of the economic benefits of infrastructure construction. RAP source is widely available in demolished construction at a very cheaper rate which then can be re-used as smart applications in infrastructures [38]. It is more elaborated in Fig. 8.

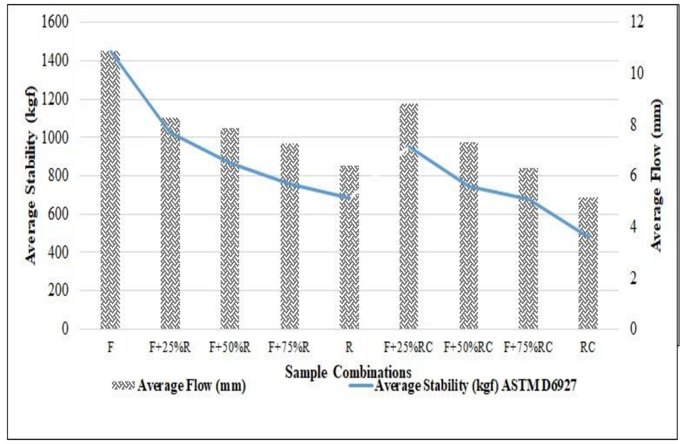

Fig. 8. Representation for VTM and OBC followed by Specifications

The properties presented for the combination of RAP + CW are in lines between the middle state of both materials keeping into the consideration of coated material of bitumen and interlocking of aggregate of CW.

7.3 Design of Conventional HMA at OBC

The aggregates in similar scenario are already experienced with the truck loads and passed with the design requirements of ESALs hence, focus may also be given in the mix design against stability checks. Particular checks are demonstrated below in Fig. 9. It should be quite evident that OBC is calculated considering three directions: content at maximum stability, maximum unit weight and in comparison, to air voids. This practice is based on standard guidelines and suitable approach for mix design.

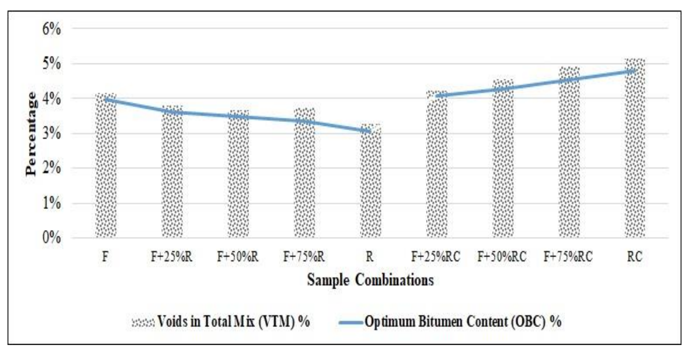

Fig. 9. Findings for Average Stability and Average Flow

According to the analysis, decreasing trends are observed for both; Average Stability and Average Flow while introducing RAP material. This is far more significant due to the chemical and oxidation processes during the ageing of the respective material. Similarly, within the combination of FA, RAP and CW, the minimum average stability is found to be about 586.36 kgf focusing 50% RAP + 50% CW. This type of trend is achieved normally when RAP & CW are subjected to simultaneous percentage of each other. Apart from that, the standard permissible limit for average stability is 805 kgf hence the observed values below the limit are considered as fail while above the limit are passed.

8. Design of Open Graded Hot Mix Asphalt Skeleton for Semi-Rigid Mix

Further to the design of HMA skeleton, voids in total mix are reproduced in accordance with the sample combinations. In order to maintain a particular amount of VTM, the number of blows for each side of a sample is kept minimum. A similar practice is adopted against three samples of each combination however the findings are presented in Table 4 below. OBC is calculated for all observed samples however voids are being maintained keeping in mind of 25%, 30% and 35%.

Table 4

Sample Combinations against OBC, Number of Blows and VTM

Sample Combinations	Optimum Bitumen Content	Number of Blows in Each Side of Sample	Achieved Voids in Total Mix (VTM) %
F	3.98%	43	25.36%
		41	30.29%
		37	35.61%
F+25%R	3.61%	43	25.76%
		39	30.33%
		35	35.58%
F+50%R	3.48%	43	25.85%
		41	31.80%
		39	35.80%
F+75%R	3.36%	43	25.92%
		41	30.82%
		39	36.08%
R	3.06%	43	26.06%
		41	30.94%
		39	36.20%
F+25%RC	4.00%	43	25.95%
		41	29.24%
		39	34.76%
F+50%RC	4.15%	41	25.70%
		39	29.39%
		37	34.90%
F+75%RC	4.38%	41	25.17%
		37	29.88%
		33	34.44%
RC	4.72%	39	25.01%
		35	29.91%
		31	35.33%

9. Empirical Analysis of Grouted and Un-Grouted Samples with Design of Semi-Rigid Mix

Samples with varying combinations of fresh aggregates, RAP material and CW are tabulated in Table 5 below in a manner that they are presenting the clear picture of recommended air voids along with the average stability at OBC and similarly accounted for grouted and un-grouted samples both. Besides that, the results are generated to opt the clear changes against different days of curing. It is clearly observed from the table below that average stability is entirely dependent on the selection of bitumen content for particular sample combination, maintain of air voids and choice of days for curing.

Table 5

Approach to the Design of Semi-Rigid Mix Sample

Design of Semi Rigid Mix								
Sample Combinations	Symbols	Average Stability at OBC (HMA)	Maintained Air Voids (VTM %)	Average Stability (kgf) Grouted Samples				
				without Grouted	3 Days Curing	5 Days Curing	7 Days Curing	28 Days Curing
F	F1	1446.57	25.36%	916.27	4137.19	4650.2	4812.96	5053.61

	F2		30.29%	613.9	4585.63	5163.42	5307.99	5679.55
	F3		35.61%	386.76	5308.91	6030.92	6193.76	6751.2
F+25%R	FR1	1028.42	25.76%	826.54	3002.99	3390.37	3515.82	3691.61
	FR2		30.33%	504.19	3260.09	3680.64	3816.83	4084
	FR3		35.58%	347.89	3774.3	4261.19	4542.42	4651.44
F+50%R	FR4	868.04	25.85%	668.27	2569.4	2903.42	2981.81	3458.9
	FR5		31.80%	447.74	2751.69	3109.41	3218.24	3420.98
	FR6		35.80%	331.33	3185.71	3599.85	3725.84	3845.07
F+75%R	FR7	754.6	25.92%	550.86	2248.71	2675.96	2769.62	2825.01
	FR8		30.82%	484.76	2392.08	2846.58	2946.21	3067
	FR9		36.08%	319.94	2769.38	3295.56	3549.32	3716.14
R	R1	685.04	26.06%	508.36	2061.97	2618.7	2710.36	2797.09
	R2		30.94%	305.02	2171.58	2757.9	2854.43	2948.63
	R3		36.20%	207.41	2514.1	3192.9	3365.32	3614.35
F+25%RC	1FRC	991.08	25.95%	756.67	3082.26	4204.2	4595.19	5017.95
	2FRC		29.24%	454	3141.72	4285.31	4503.86	4747.07
	3FRC		34.76%	304.18	3637.26	4961.23	5244.02	5438.05
F+50%RC	4FRC	843.6	25.70%	573.65	2624.44	3428.83	3771.71	4050.82
	5FRC		29.39%	372.87	2674.21	3493.86	3913.12	4085.3
	6FRC		34.90%	261.01	3096.01	4044.94	4186.51	4450.26
F+75%RC	7FRC	728.7	25.17%	502.8	2260.84	3061.18	3348.93	3405.86
	8FRC		29.88%	372.07	2309.98	3127.71	3416.71	3519.21
	9FRC		34.44%	260.45	2674.33	3621.04	3747.78	4028.86
RC	1RC	586.36	25.01%	404.88	1917.4	2435.09	2549.54	2766.26
	2RC		29.91%	263.17	1970.17	2502.12	2644.74	2761.1
	3RC		35.33%	223.7	2151.94	2732.97	2802.66	3057.7

The trends of the analysis may also be clearly understood using the Fig. 10 below.

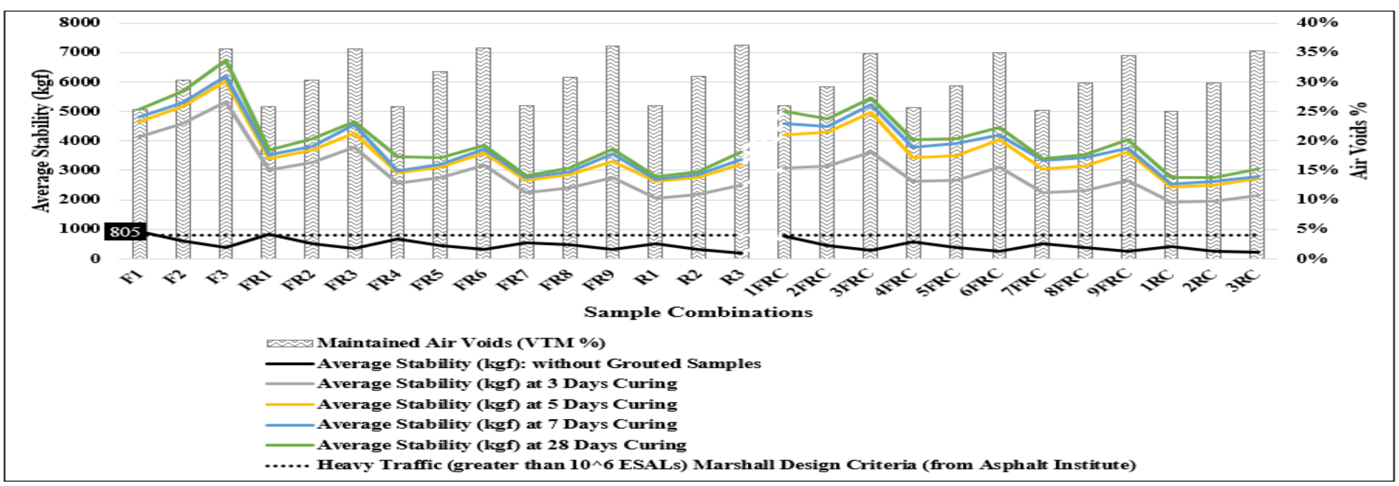

Fig. 10. Design of Semi-Rigid Mix

In case of un-grouted samples for the combination of FA and RAP, it is monitored that with the increase in maintained air voids, average stability is substantially decreasing due to the vacuum produced in the samples. The samples without grouting are pertaining to the less stability as it reflects low strength and durability due to increase in air voids. However, for the case of grouted samples, it is obvious that with the increase in maintained air voids, more material in terms of cement & sand shall be required. The above graph is highlighting the clear shreds of evidence for all types of combinations. Un-grouted samples are highlighted below the marginal line. In-fact, the rest of the combinations are passing the specified limits even after curing for different days. The average stability of the samples may vary with respect to days of curing therefore the selection of material will be accordingly adjusted in similar fashion. Interesting results are attained while comparing both of them specifically on the observations of average stability. Cement grouted samples has got enhanced stability and its value is continuously increasing subject to the rate of curing i.e. 3 days, 5 days, 7 days and 28 days as per the recommended guidelines. In practical conditions, it is more difficult for operational pavements to maintain the curing time of 28 days and even 7 days but considerable rate of stability is also achieving particularly in 3 days only (as per the experimentations).

10. Cost Considerations for 1km Road Section

In continuation to the recommended sample combination of 100% RAP with 0% fresh aggregates, the density of aggregates and compacted volume are set out as 2550kg/m^3 and 1050m^3 respectively. Focusing a 250m^3 dumper cost (market price), the overall material used, and its estimated expenditure are exhibited below in Table 6.

Table 6

Material and Cost Analysis

Aggregate Compacted Volume (cum)	1050
Material 250m^3 dumper	4.2
Cost of 250m^3 dumper (aggregate) PKR	22,000/-
Total cost of material (aggregate) PKR	92,400/-

Here it is quite obvious from the above table that total cost incurred for aggregate material in terms of dumper is about 92,400 PKR for 4.2 dumpers approx. Hence, this amount could be easily saved if 100% RAP option is availed for only 1km road section. Besides that, further cost analysis may be carried out for multiple kilometres in normal road construction.

11. Conclusion

As highlighted in the initial sections of the research paper that the complete findings are presented in a manner to focus on the strategic analysis of semi-rigid pavement. Use of semi-rigid pavement construction is common in the industry but the combination of the same with recycled materials is observed as the economical aspect of this type of pavement. Similarly, the study aim resembles with the specific agendas like characterization of semi-rigid pavement, use of recycled/RAP material followed by the significant cost considerations. Nevertheless, the extended analysis is presenting the clear contribution for the stakeholders to which may be utilized in consideration to the nature of work, and it is also the novelty of the research. The analysis is carried out in detailed for sieve analysis in which clear relationship is achieved between particle sizes and percentage passing for set of combinations. In case of 50% RAP + 50% CW; the reference line is beyond the graphical limit. The properties which are evaluated in different portions of the study are interconnected with each other which then ultimately providing the idealized concept towards the mix design approach of semi-rigid pavement. Experimental protocols are established in a way to develop the understanding of key controls with respect to all constituents of subject pavement. Within this perspective, parametric properties are explored for possible material arrangements against aggregates, bitumen and grouting materials [39]. In this connection, the important parameters is the findings related to specific gravity. As specific gravity reveals it ratio of the material's density to the density of water therefore a balanced proportion of about 3% is achieved in the case of 50% FA & 50% RAP. Not only that, but the study is also focused on the maximum use of recycled material in comparison to the limited use of such materials specially to design semi-rigid pavement. The combinations are derived in accordance with the standard percentages of FA, RAP and CW. Therefore, the idea of semi-rigid pavement with recycled materials is critically analyzed and presented in terms of said mix design. The focus is on 100% replacement of fresh aggregates and providing a framework for relevant practitioners. Complete process is interpreted for selecting optimum bitumen content in specified combinations of aggregates and recycled material. Besides that, it is also dependent on the material's source and standardization of RAP material and CW [40]. At the later stages of the analysis, a detailed comparison is drawn for grouted and un-grouted samples ensuring the complete design of semi-rigid mix. Considering 100% RAP and 50% RAP + 50% CW, maximum stability is 3614 kgf and 3057 kgf respectively against 28 days curing. In practical situation, 28 days curing is not realistically possible but significant and sound results are also obtained in the case of 3 days and 5 days curing for which the particular design may be governed. It may be concluded that recycled materials are available all around but there is a need to opt the materials which are more pertinent to use within the semi-rigid mix through specific mechanisms, standard experimentations, and critical analysis. In continuation to the cost considerations, the cost of Fresh Aggregate is also variably increased to 37.5% with in the year (as per current market rates) which is a matter great concern for the stakeholders.

12. Recommendations

As a matter of fact, the research is designed to appraise all characteristic parameters of semi-rigid pavement through material aspects and with the use of recycled materials. Use of recycled materials in semi-rigid pavement also shows its efficiency in terms of incurred cost of infrastructure. In parallel, the future recommendations and formulated guidelines from overall research may be addressed as follows:

1. It is a matter of great concern to promote such significant materials in pavement construction specifically within the use of semi-rigid pavement. The novelty to use recycled materials in semi-rigid pavement should correspond to the smart and sustainable applications in infrastructures.
2. The susceptibility of material to be used in semi-rigid pavement is dependent on associated factors and experimental protocols that should be checked thoroughly during the entire working phase. The existing literature entails the evaluation for semi-rigid pavement, but the measures and framework analysis are produced in this research within the context of the use of different recycled materials.
3. It is also important to analyze the complete parametric properties of target materials in semi-rigid pavement likewise in this case of its use with recycled materials. The properties are assessed for recycled materials like RAP and CW.
4. Parametric properties are drawn on the set of observations for aggregates, bitumen, and grouting material. These properties are monitored on the basis of standards while the specific results are formulated focusing the usability of selected materials.
5. The choice of grouting material should correspond to the standard specifications of subject pavement type. Furthermore, grouted, and un-grouted samples are derived and represented for clear comparison.
6. Grouting material is taken into account for setting times and specific gravity highlighting its comparison with standards.
7. Likewise, the specific grade of bitumen should be identified keeping in view of its dependent factors. Similar practice is adopted in the research for the selection of bitumen grade.
8. Findings are revealed for bitumen characteristics while bitumen is assessed only for 80/100 grade.
9. This type of research is validated to provide optimal solution for stakeholders in terms of strength, durability and cost-effectiveness of semi-rigid pavement.
10. Particular requirement of semi-rigid pavement in industrial sector is considered with its applicability to the material with respect to the type of construction. The use of construction material is also associated with the on-site availability.
11. The type of semi-rigid pavement is identified with its advancements in infrastructure design and construction. The respective area is justified using different combination of materials through literature. Results are being monitored for all set of combinations providing the individual guidelines in the research.
12. Perhaps, the design limits for semi-rigid pavement are also defined in context to fatigue failures, material requirements, traffic flow characteristics and other governing factors.
13. Similarly, the area is more focused with the use of RAP material and CW in semi-rigid pavement. Standards are set out for the same to meet the minimum requirements. More accountable results are originated when varying percentages are addressed ensuring its economical use in semi-rigid pavement.
14. Nevertheless, the criteria is heading towards its implications in Job Mix Formula for stream of observations.
15. Furthermore, the overall working predominates the criteria of job mix formula to be taken as an initiative and approach formula for semi-rigid pavement.
16. Analytical justifications are also developed on achieved blend grading for different combinations. Certain variations in the analysis are observed while focusing the cross parameters of VTM, VFB, VMA and stability. Therefore, the choice of material in this connection shall also be dependent on stability requirements, meteorological conditions, topography of the area and economical bindings.

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