Development of a Sustainable Semi-Flexible Pavement Composite Containing Recycled Asphalt Pavement

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ABSTRACT: The purpose of this research is to investigate the feasibility of Recycled Asphalt Pavement (RAP) material in developing sustainable Semi-Flexible Pavement (SFP) composite material. While a lot of effort has been made in the last several years to explore the potential of RAP in bituminous and cement concrete pavement, such an attempt has not been made for emerging alternative pavement structure, such as SFP. SFP holds a unique ability to combine flexibility and rigidity which offers improved durability and performance. In this study, RAP material was integrated into the SFP mix to enhance sustainability while minimizing the dependance on virgin materials. Along with mix design part, different mechanical properties related to strength and durability of SFP composite were evaluated in the laboratory. Various RAP contents (0%, 25%, 50%, and 75% by weight) were assessed to understand their impact on performance. Results indicated that RAP significantly improved the sustainability component of the SFP while maintaining adequate mechanical performance. Particularly, limited laboratory findings indicated reduction in energy requirement with increase in RAP proportion in SFP composite. In addition, increase in RAP content to 75% also satisfied the strength and durability based requirements. The findings demonstrate that this approach can potentially reduce the environmental footprint of road construction while providing a long-lasting pavement solution.

1. INTRODUCTION

Permanent deformation, moisture damage, etc., are some of the major concerns with asphalt pavement. Similarly, poor riding quality, heat generation due to friction, etc., are major concerns with cement concrete pavement. Nevertheless, both of these conventional pavements have their own advantages. Therefore, an attempt was made in the past to develop composite material that holds the advantages of asphalt as well as cement concrete pavement while addressing major drawbacks with respective pavement types. As a result of this thought process, Semi-Flexible Pavement (SFP) was developed, combining the benefits of asphalt and cement concrete pavement. SFP essentially consists of a porous asphalt skeleton filled with cementitious grout material. The asphalt mix part provided flexibility, while the cementitious grout phase provides strength to such composite material. Traditionally, the porous asphalt skeleton of SFP is prepared with the help of fresh asphaltic material. As a result, it holds serious environmental concerns. At the same time, it also provides an opportunity for researchers to look into alternative options for fresh asphalt mixtures to improve the sustainability quotient of SFP-based composite material. In this direction, one of the ways to address this problem could be the utilization of existing end of life materials from the road sector, such as Recycled Asphalt Pavement (RAP) in the construction of SFP composite.

It is important to note that reported research works on SFP have predominantly focused on enhancing the performance characteristics of SFP, such as deformation resistance, durability, and adaptability for heavy-load applications [*1*-*3*]. While research works on such performance-based parameters are extremely important, improving the sustainability of such composite material based pavement material is equally important. Unfortunately, very few researchers have attempted to improve the sustainability of SFP composite. For example, Cai et al. [*4*] investigated the potential application of cold mix asphalt-based material for the porous asphalt part of SFP so that the heating requirement can be completely avoided and, hence, the sustainability part could be improved. However, to the best of the knowledge of the authors, none of the reported studies have explored the potential application of RAP material in developing SFP-based composite material. On the other hand, the use of RAP material in conventional asphalt mixture, cement concrete layer as well as in the aggregate layer of pavement structures has been explored extensively by several researchers over the last several years [*5*-*8*].

Considering the motivation and research gap presented above, this research work aims to explore the suitability of RAP material in developing a porous asphalt skeleton of SFP composite. Along with the mix design of RAP-based porous asphalt structures, additional aspects such as formulating suitable cementitious grout material for subsequent grouting and the mechanical properties of the finally prepared SFP composite have been explored and discussed in this research work.

2. MATERIALS

The virgin asphalt binder (VG-30) utilized for this study was collected from IndianOil Total Pvt. Ltd. Recycled Asphalt Pavement (RAP) was obtained from milling operations on the Kanpur-Hamirpur highway, which is situated in the central part of India. The RAP material was initially processed using the Los Angeles Abrasion machine to minimize agglomerates and sieved to obtain particles with a specific size range suitable for use in the targeted porous asphalt mixture skeleton for subsequent cementitious grouting. Virgin aggregates were sourced from the NHAI site near Unnao Kanpur, India. The grout material was designed in the laboratory considering its flow and strength criteria to fill the voids in the porous asphalt concrete skeleton. The grout consisted of Ordinary Portland Cement (OPC), fine sand, silica fume, and fly ash to contribute to sustainability and carboxyl-based superplasticizers to achieve a flowable, high-strength material with enhanced durability.

3. MIX DESIGN OF SFP COMPONENTS

3.1. Mix Design of Porous Asphalt Mix Skeleton

The porous asphalt mix skeleton was designed with the objective of achieving 30% air voids to facilitate grout infiltration. It is to be noted that no standard gradation limit exists for SFP-based porous asphalt mix skeletons. Therefore, aggregate gradation was selected based on trial runs, ensuring optimal air void content with standard compaction efforts (Fig.1). The plot clearly indicates that the selected aggregate falls under a uniform gradation category where the majority of the aggregate proportion is of similar size. The mix incorporated varying proportions of RAP: 0% RAP (control), 25% RAP, 50% RAP, and 75% RAP by weight of total aggregates. The binder content was optimized using the draindown test as per ASTM D6390, ensuring that the drained binder content did not exceed the permissible limit of 0.30% by the total mix weight. Each mixture was compacted (only on one face using a Marshall compactor) and evaluated for air void connectivity through permeability tests to ensure sufficient voids for grout infiltration. The number of Marshall blows for different compacted specimens was decided to attain a target air void of 30%.

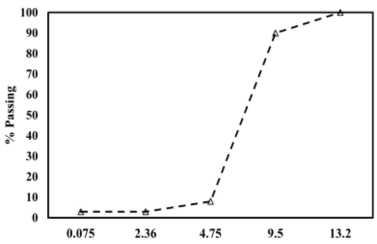

Fig.1: Aggregate gradation for porous asphalt skeleton

3.2. Mix Design of Cementitious Grout

The grout used in this study was designed to ensure adequate workability and strength for the final SFP composite. It was composed of Ordinary Portland Cement (OPC), fine sand, fly ash, silica fume, and a superplasticizer. The proportions of these components were optimized based on workability and strength through a series of laboratory experiments. Table 1 provides a summary of different grout combinations. Grout flowability was evaluated using a flow cone test as per ASTM C939, with acceptable flow times ranging from 10 to 16 seconds. Compressive strength was tested according to ASTM C109, targeting values more than 40 MPa, while flexural strength was measured per ASTM C348, ensuring a minimum value of 3 MPa. The material composition was thoughtfully varied to achieve flow and strength-based criteria, as highlighted above.

Table 1: Grout combinations*

Grout Type	W/C	S/C	FA/C	SF/C	SP
A	0.35	0.2	0.1	0.025	0.01
B	0.4	0.2	0.1	0.025	0.01
C	0.45	0.2	0.1	0.025	0.01
D	0.5	0.2	0.1	0.025	0.01
E	0.4	0.2	0.1	0.025	0.5
F	0.45	0.2	0.1	0.025	0.5
G	0.35	0.2	0.2	0.025	0.01
H	0.4	0.2	0.2	0.025	0.01

**W/C: water-cement ratio; S/C: sand-cement ratio; FA/C: Flyash-cement ratio; SF/C: Silica fume-cement ratio; SP: Superplasticizer*

4. PREPARATION OF SFP COMPOSITE

Once the mix design of the porous asphalt skeleton (with different RAP compositions, as mentioned before) and cementitious grout were over, the next step was to prepare the SFP composite by grouting the porous asphalt mix. For this purpose, several compacted porous asphalt skeletons were prepared using pre-identified binder content. Specially designed split moulds were fabricated for this research work. Subsequently, grouting was done with the selected grout composition. It was poured carefully into the pre-compacted porous asphalt skeleton. The whole setup was covered using a plastic sheet and was left undisturbed for 48 hours before de-moulding. The excess grout material on the top of the specimen was scrapped off using a sharp edge spatula after about 6-8 hours of grouting. Upon de-moulding, samples were wrapped using a moist cotton cloth and kept under an airtight zip-log bag for curing. The humidity level was measured within the bag and was consistently found to be in the range of 95-98% for all specimens during curing. The penetration of grout in the specimen till the bottom of the porous asphalt skeleton was ensured through visual observation and volumetric calculation on available air void in the porous skeleton and the volume of the penetrated grout material (penetration value for different sample combinations were comparable). Specimens were also cut across the depth as well as across cross-section at different depths to visually observe and confirm the maximum degree of grouting to the porous asphalt skeleton.

5. RESULTS AND DISCUSSION

5.1. Effect of RAP on Optimum Binder Content

Fig.2 shows the variation of optimal binder content for different porous asphalt mix skeletons (0%RAP to 75%RAP). It is evident from the plot that the additional virgin binder content required to satisfy the drain down-based criteria (max. 0.3% by the wt. of the porous asphalt mix) decreased from 4.62% to 3.67%. Such a response can be attributed to residual asphalt binder present in the RAP mix. Therefore, as the RAP content increased, the proportional requirement of additional binder content decreased to satisfy the drain down-based requirement. The authors also believe that the overall effective binder content (additional virgin binder plus residual binder in RAP) increased with the increase in RAP proportion.

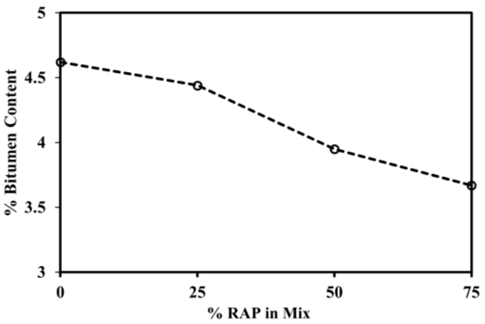

Fig.2: Optimum binder content

5.2. Influence of RAP on Compaction Effort

The number of Marshall blows required to achieve target air void for different mix combinations is presented in Fig.3. It is interesting to observe that the compaction effort required to achieve target air void substantially decreased from 75 blows for the control mix to about 21 blows for mix containing 75%RAP. Such a response could be believed due to a proportional increase in effective binder content in the RAP-based porous asphalt skeleton (i.e., the virgin binder plus residual binder content in the RAP), as highlighted in the previous section. As a result, the degree of lubrication effect proportionally increased with the increase in RAP proportion in the porous asphalt skeleton. This led to the need for proportionally lower compaction effort. Such a response is also important to look at from a sustainability angle because the amount of energy required to achieve the required degree of compaction will be reduced and, hence, a complimentary change along with the utilization of RAP waste.

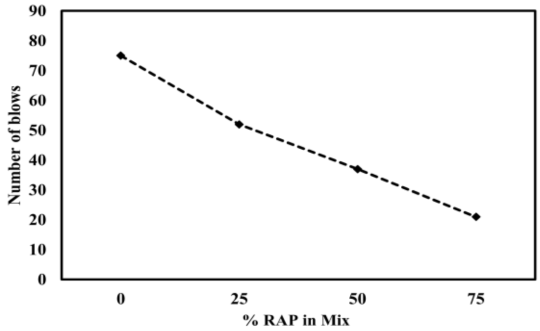

Fig.3: Plot for optimal compaction effort

5.3. Optimization of Grout Composition

The details of each grout composition, A through H, are provided in Table 1. In order to achieve the desired balance of flow time and compressive strength, different grout compositions were examined with adjustments in water-cement ratio, fly ash content, and a fixed sand cement ratio of 0.2. Flow time (with target value between 10 to 16 sec.) and compressive strength (min. 40 MPa for 28 days cured specimen) were measured for each grout composition. As shown in Fig.4(a) and 4(b), grout type B achieved optimal performance, with a flow time of 11 seconds and a compressive strength of 45 MPa. This balance indicates that the selected "*grout type B*" provides both adequate workability and sufficient strength, making it suitable for semi-flexible pavement applications.

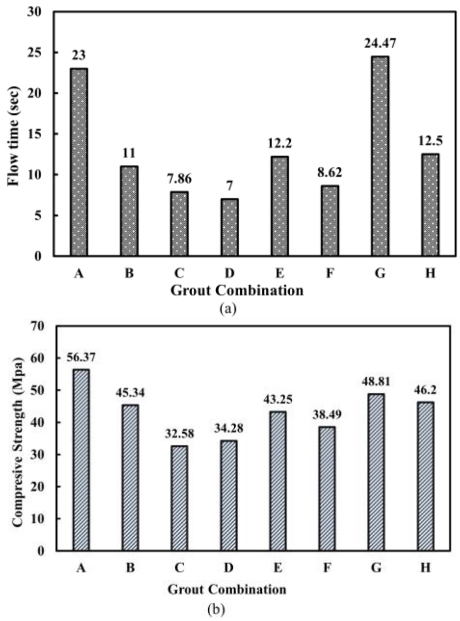

Fig.4: (a) Flow time, (b) compressive strength

5.4. Performance Evaluation of SFP Composite

Role of RAP in changing the ITS strength: The Indirect Tensile Strength (ITS) test was conducted to determine the tensile strength characteristics of SFP composite specimens. Fig.5 shows the variation of ITS of various sample combinations considered in this research work (an average of three replicates is reported). Results showed that ITS values increased as RAP content increased, with ITS value increasing from 1.48 MPa for the 0% RAP mix to 1.691 MPa for the 75% RAP mix, indicating a marginal gain of approximately 12%. Such a response can be attributed to the relatively stiffer nature of RAP compared to the virgin mixture. Such a response clearly indicates that while cement grout is primarily responsible for imparting strength, incorporating RAP into porous asphalt skeleton will not hamper the strength parameter of SFP composite. These experimental results also highlight that the strength of SFP-based composite is significantly higher than usually observed for conventional asphalt mixtures.

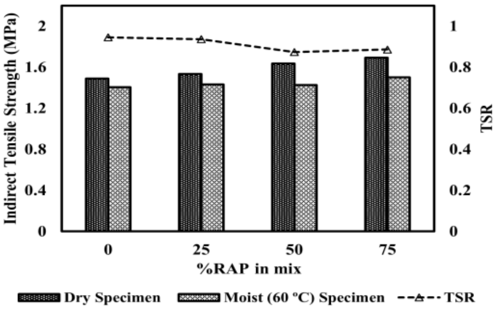

Fig.5: Indirect Tensile Strength and TSR value

Role of RAP in changing the moisture damage resistivity: The moisture damage resistivity of SFP composite was evaluated using the conventionally utilized ITS-based Tensile Strength Ratio (TSR) approach. The variation in TSR value is presented in Fig.5. The variation in TSR value reveals a slight decrease in TSR value as RAP content increased from 0.945 at 0% RAP to 0.886 at 75% RAP. It is important to note that the interface bond strength between the cementitious grout phase and the asphalt binder in the porous asphalt skeleton phase has an important role to play when it comes to the damage induced by such composite material in the presence of water. It is also reasonably known that the interface bond strength decreases with the increase in the degree of ageing of asphalt binder. The above discussion provides one of the possible justifications for a slight decrease in TSR value with an increase in RAP content in the SFE composite. Nevertheless, it is also evident that despite this decrease, the TSR value remained above the commonly accepted threshold of 0.80, commonly accepted for adequate moisture resistance. Such a response clearly indicates that the semi-flexible pavement mix retains sufficient tensile strength against moisture damage even at higher RAP contents.

Role of RAP in changing the durability-based property of SFP composite: The Cantabro abrasion loss test was conducted for this purpose (an average of three replicates is reported). The experimental results of the Cantabro loss test indicated a slight increase in material loss with higher RAP content. Specifically, material loss rose from 16.37% in specimens with 0% RAP to 19.68% in specimens with 75% RAP. This marginal increase in Cantabro loss indicates that although RAP content can slightly increase the abrasion susceptibility, the overall durability of the semi-flexible pavement will remain satisfactory. The slightly higher material loss with increased RAP may be attributed to the aged binder within RAP, which has a stiffer and potentially more brittle structure compared to the control SFP.

6. CONCLUSION

This study explores the feasibility of incorporating high proportions of Recycled Asphalt Pavement (RAP) into Semi-Flexible Pavement (SFP) systems to achieve sustainable and efficient pavement solutions. RAP inclusion significantly reduced the binder content and compaction efforts while preserving key mechanical properties. While higher RAP content introduced slight increases in abrasion susceptibility and lower Tensile Strength Ratio (TSR) under moisture conditions, these values were found to be within acceptable limits, affirming RAP's viability in SFP applications. Therefore, this research provides an initial indication for the utilization of RAP material in SFP systems.

7. REFERENCE

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