sustainability

MDPI

Article

Impact of Crumb Rubber Concentration and Plastic Coated Aggregates on the Rheological Performance of Modified Bitumen Asphalt

Arun Kumar [1,*], Parveen Berwal [1], Abdullah I. Al-Mansour [2], Mohammad Amir Khan [1,*], Shamshad Alam [2], Seongkwan Mark Lee [3], Akash Malik [4] and Amjad Iqbal [5,*]

1 Department of Civil Engineering, Galgotias College, Greater Noida 201306, Uttar Pradesh, India; parveenberwal@gmail.com
2 Department of Civil Engineering, College of Engineering, King Saud University, P.O. Box 800, Riyadh 11421, Saudi Arabia; amansour@ksu.edu.sa (A.I.A.-M.); salam@ksu.edu.sa (S.A.)
3 Research Institute of Korea Road Facilities Safety Industry Association, Seoul 04901, Korea; marklee0313@gmail.com
4 Department of Civil Engineering, Galgotias University, Greater Noida 201306, Uttar Pradesh, India; akashmalik032@gmail.com
5 Department of Advance Materials and Technologies, Faculty of Materials Engineering, Silesian University of Technology, 44-100 Gliwice, Poland
* Correspondence: arun.kumar764@gmail.com (A.K.); amirmdamu@gmail.com (M.A.K.); amjad.iqbal@polsl.pl (A.I.)

Abstract: The diminution of natural resource exploration, the retrieval of waste, and the structural modification of polymers by additives are the main contributions to sustainable development. The properties of bitumen are enhanced by the crumb rubber through effective bitumen modification techniques, which have environmental and economic advantages. In this study, plastic waste, plastic-coated aggregate (PCA), and bitumen were blended in order to enhance the engineering properties of the flexible pavement. In order to compute the composition of crumb rubber modified bitumen (CRMB), the adopted materials were subjected to the relevant experiments. PCA was a very effective material when compared to the standard bitumen road pavement. The recycling of waste crumb rubber and plastic was tested by adding them into the hot mix asphalt. The Marshall properties of standard (virgin) bituminous mix, CRMB grade 55, and plastic mix asphalt were studied in detail to explore the solutions for a sustainable environment. The comparison was performed between these two materials with the standard bitumen, which resulted in the CRMB and plastics being found as the most effective additions with robust properties such as low-cost material, high strength, long life usage, and un-harmful to nature. The optimal bitumen content was found to be 6.166%, 6.1%, and 5.833% for standard bitumen, crumb rubber modified bitumen, and plastic-coated aggregate, respectively.

Keywords: bitumen; flexible pavement; plastic coated aggregate; waste rubber; waste plastic

check for updates

Citation: Kumar, A.; Berwal, P.; Al-Mansour, A.I.; Khan, M.A.; Alam, S.; Lee, S.M.; Malik, A.; Iqbal, A. Impact of Crumb Rubber Concentration and Plastic Coated Aggregates on the Rheological Performance of Modified Bitumen Asphalt. *Sustainability* **2022**, *14*, 3907. https://doi.org/10.3390/su14073907

Academic Editor: Byungik Chang

Received: 2 March 2022
Accepted: 23 March 2022
Published: 25 March 2022

1. Introduction

Pavements or roads are an important part of the development of a country. Their importance in a country can be compared to the importance of arteries in a human being, and their importance in the development of a country can never be ignored. A well-developed and well-maintained network of roads and an effective transportation system are, therefore, essential for the economic growth and industrial development of a country. India is a developing country; the infrastructure facilities used in present times in the transportation sector are not good enough to treat it as a better communication system. In addition, the need for good and well-maintained roads and highways is increasing day by day, and to enhance the economic development of this country, we shall have to focus on the development of the transportation sector of the country. At present, in India, road construction is majorly flexible bituminous pavement or rigid pavement. This is because the organizations related to road construction are constructing pavements without making any attempt at the pavement selection process or making any comparative analysis.

In this process, rubber is recycled and used in the pavement, which gives high fatigue resistance and better adhesion between aggregates and bitumen [1,2]. Crumb rubber modified bitumen (CRMB) is a hydrocarbon binder that is obtained through the physical and chemical interaction of crumb rubber with bitumen [3,4]. Modified bitumen can be soft in the summer and brittle in the winter [5]. It provides protection during extreme weather conditions and heavy traffic loads. Crumb rubber is used to seal cracks and joints during hot weather conditions. The mixture of crumb rubber and bitumen helps in achieving better performance for the wearing course [6–8]. Hence, the process of mixing bitumen with crumb rubber to meet the required performance standards of the pavement appears to be a logical and economical approach.

Plastic has become part of our modern lifestyle. It is used for packaging, protecting, serving purposes, and even discharging all types of goods. Disposal of plastic waste has become a major threat to the environment and, due to the increasing rate of road traffic, it has become very necessary to increase the road bearing capacity and performance. Therefore, utilization of plastic waste in flexible pavement has become a well-calculated method of solving the above problems.

On a highway, the major problems are potholes and corrugation. Plastic pavement will be a better solution to the issues stated above. A material consisting of one or more organic polymers having a large molecular weight, solid in its finished state, and able to be shaped by its flow, is called "plastic" [9]. Plastic has high durability, and it degrades very slowly [10]. There are mainly two types of plastic: thermosetting and thermoplastics. Because thermo-setting plastic solidifies irreversibly when heated, it has high durability and strength, and it can be used primarily for construction applications. Plastic is a non-degradable waste, and it causes the greenhouse effect and global warming. Various experiments have been conducted and several are still going-on on the topic of how waste plastic can be reused productively [11]. Various studies show that when aggregates are heated with shredded plastic waste, a fine coat of plastic forms and, when mixed with a binder such as bitumen, it has higher strength and resistance [12].

Literature states that modification of bitumen can be performed through a dry process or a wet process. In the dry process, rubber granules are added to the mineral mix, which sets the aggregate fractions. The dry method adds rubber that has a grain size of 0–2 mm, in the amount of 2–3%, where a mixture with rubber dust inclusions is obtained. Rubber increases the material's stiffness, and its addition also increases the resistance to cracking. The second is the wet process, which includes adjusting the asphalt binder to rubber dust. The addition of rubber dust is about 15% of the asphalt mass. Furthermore, this mixture is heated from 190 to 230 °C for 40–50 min [13].

The rutting resistance, resilience modulus, and toughness of asphaltic can be increased via the wet process and crumb rubber modifications. The major reason for the improved properties is the interchanges in the viscosity, softening point, and the swelling process of rubber that binds with bitumen [14–16]. The literature shows that this swelling is 3–5% to its original size due to extensive absorption of bitumen components [17,18]. CRMB is vulnerable and is dependent on exterior factors such as the mixing temperature, mixing duration, and type, and internal factors such as type of bitumen, crumb rubber quantity, particle size, and type. Therefore, that is why accuracy is required for productive results.

On heating at 100–150 °C, plastics such as polyethylene, polypropylene, and polystyrene soften and show good binding properties. Blending plastic with bitumen results in a mix that is amenable for road laying. Viscosity increases continually at 150 °C and at 175 °C or 200 °C, and the viscosity initially increases rapidly, then reduces its pace, and subsequently decreases [19]. These roads have endured loads due to traffic, heavy rain, and variation of temperature.

The robust properties obtained from materials depend on the stoichiometric calculation of reactant. A specified amount of bitumen was used in CRMB and PCA, and the findings demonstrate a tremendous stability proportion that has yet to be reported in the literature. Furthermore, CRMB is common practice for enhancing the bitumen properties, but use of waste and harmful plastics for modification of bitumen is the least discussed topic. Our article reported maximum stability with least bitumen percentage content through plastic modified bitumen.

Secondly, if waste plastic along with bitumen is used, its life and smoothness will increase. This process is economical as well as eco-friendly [15]. The process of adding shredded plastic waste in the construction of roads reduces plastic shrinkage and drying shrinkage. This process also improves the abrasion and slip resistance of asphalt roads. As the climate of India is hot and humid, using plastic pavements in place of regular asphalt pavements is of great advantage.

The objective of the present study was to utilize plastic and rubber wastes for modification and enhancement of the mechanical properties of asphalt that are cost-effective, eco-friendly, and sustainable.

2. Materials and Methods

This study includes investigation on the Marshall properties of standard (virgin) bituminous mix, crumb rubber modified bitumen (CRMB) grade 55, and plastic mix asphalt prepared in the laboratory. As in the CRMB, the percentage of crumb rubber or waste tire rubber was used as 8% of the weight of bitumen. Plastic was used as 8% of the total aggregate weight in the asphalt mixture. VG30 type of bitumen from Indian oil company limited, petrochemical plant Panipat (India), was used in this research. The effectiveness of CRMB was checked by comparing the results of tests conducted on normal specimens and then comparing plastic mix asphalt with normal or standard bitumen. All the tests on aggregates, standard bitumen, and CRMB were performed following the American Association of State Highway and Transportation Official (AASHTO) and American Society of Testing Material (ASTM) for testing standards. Various laboratory tests were conducted on these ingredient materials to determine their physical properties and to check whether they can meet common specification limits. Tests were performed for assuring the quality of materials, including size variation tests and specific gravity tests. The tests performed on the standard bitumen and CRMB sample include penetration test, flash point test, fire point test, ductility test, viscosity test, softening point test, and specific gravity test [20–25]. Sieve analysis of aggregates was performed according to the type of grading required as per standards (type-III) for the wearing course of the pavement. The variation of bitumen content in samples taken (% by weight of total aggregate) was between 4.5–6.5%.

After that, the asphalt mixture is prepared with varying quantities of bitumen and crumb rubber to obtain optimum bitumen content by the Marshall test. The Marshall test was used to check the properties of these crumb rubber modified bitumen (CRMB) mixes and plastic mix asphalt [26]. Finally, the test results obtained via lab tests are studied and analyzed in Table 1.

2.1. Marshall Test of Mix Design

In the Marshall method, a compacted bituminous mixture of cylindrical shape is axially loaded at a rate of deformation of 50 mm/min, and the amount of resistance given by the cylindrical bituminous mixture specimen to this axially acting load is measured. The two major features of this method are (i) density-voids analysis and (ii) stability-flow tests. The maximum amount of loading that the bituminous specimen can undergo at standard temperature (60 °C) is known as the Marshall stability of the mixture. The maximum changes in length that the bituminous specimen undergoes at the maximum loading condition is called its flow value. Flow is measured in 0.25 mm units. In the Marshall test, our objective is to produce the best suitable binder content for the aggregate mixtures that are applied.

Table 1. Various tests and their experiment results.

S.NO	Particulars	Avg.	Standard Deviation
1	Specific gravity (G) fine aggregate	2.67	0.13
2	Specific gravity (G) coarse aggregate	2.69	0.05
3	Aggregate impact value	25.06	0.63
4	Percentage of wear (abrasion value)	33.2	0.16
5	Specific gravity (standard)	1.039	0.00
6	Specific gravity (CRMB)	1.02	0.01
7	Viscosity in seconds (standard)	4′58″	0.04
8	Viscosity in seconds (CRMB)	4′35″	0.02
9	Softening point of bitumen (standard)	52.5 °C	1.00
10	Softening point of bitumen (CRMB)	66.5 °C	0.50
11	Flashpoint of bitumen (standard)	305 °C	-
12	Fire point of bitumen (standard)	310 °C	-
13	Flashpoint of bitumen (CRMB)	249 °C	-
14	Fire point of bitumen (CRMB)	256 °C	-
15	Ductility (standard)	100	0.00
16	Ductility (CRMB)	80.33	1.25
16	Penetration value (standard) (0.1 mm)	55.66	3.86
17	Penetration value (CRMB) (0.1 mm)	24.33	0.47

2.2. Implemented Steps and Procedures for Experiment

Prior to sample formation, several steps were performed and repeated twice to minimize errors in the results. The selection was made for the required size of aggregates and the quantity of the aggregates was measured. The specific gravity of all aggregates and asphalt cement was determined by varying the amount of asphalt in the different specimens. Every specimen has its own properties, and to explore the potential of the prepared sample, specific gravity and stability was performed. The next step involved the calculation of void percentage, and from the obtained data, the selection was made for optimum binder content. All the designs were checked according to the design requirements.

Conclusively, four binder contents were prepared by varying the amount of bitumen in each one of them. Of all this binder content, three samples were created from each of them. All the samples are subjected to the following tests:

- Test for determination of bulk density.
- Test to check stability and flow.
- Test for analyzing the density and voids of the sample

2.3. Preparation of Specimen for Testing

The quantity of all the materials to be mixed was taken according to the relevant standard. To produce a compact bituminous mix specimen that had a thickness of approximately 63.5 mm, 1200 g of aggregates and filler materials were used. The mixture of aggregates is heated from 175 °C to 190 °C. The mould and rammer were cleaned and heated to a temperature of about 100 °C to 145 °C [21]. The binder, i.e., bitumen, was heated to between 121 °C to 138 °C [27]. The machine used (Marshall stability machine) is shown in Figure 1. The required quantity of the binder i.e., bitumen, is added to the mixture of aggregate and is thoroughly mixed. The entire mixture of bitumen and aggregate was placed in the required pre-heated mould and compacted with a hammer with the number of blows specified. When the molding was finished, the removed samples were left to cool down.

Figure 1. Marshall Stability and flow test setup.

Optimum binder content is selected as the average binder content for maximum density, maximum stability, and specified percent air voids in the total mix (Equation (1)). Thus,

$$B0 = \frac{B1 + B2 + B3}{3} \quad (1)$$

where,

$B0$ = optimum Bitumen content.
$B1$ = % asphalt content at maximum unit weight.
$B2$ = % asphalt content at maximum stability.
$B3$ = % asphalt content at specified percent air voids in the total mix.

3. Result and Discussion

3.1. Standard Bitumen Calculation

The various tests performed for the calculation of bitumen quantity is as per Table 2.

Table 2. Various test values of standard bitumen.

Bitumen Content (%)	Void Mineral Aggregate	% Air Voids	Stability (N)	Flow (mm)	Unit Wt. (gm/cm^3)
4.5	13.87	9.82	3534	0.33	2.31
5	13.646	9.1	4371	0.42	2.328
5.5	13.75	8.726	5096.4	0.54	2.338
6	13.85	8.35	6240	0.67	2.372
6.5	13.99	8.01	5338.2	0.88	2.345

Optimum bitumen content for standard bitumen is 6.166%.

3.2. Crumb Rubber Modified Bitumen Calculation

Crumb rubber mixed with bitumen as per the specified percentage and various test performed. Data are as per the Table 3.

Table 3. Various test values of CRMB specimen.

Bitumen Content (%)	Unit Wt. (gm/cm^3)	Void Mineral Aggregate	% Air Voids	Corr. Stability (N)	Flow (mm)
4.5	2.2	14.71	10.67	3268	2.2
5	2.17	14.81	10.33	4730	2.7
5.5	2.28	14.92	9.96	7031	3.05
6	2.54	15.17	9.77	6510.4	3.32
6.5	2.32	15.28	9.4	5108.6	3.42

Optimum bitumen content for CRMB is 6%.

For CRMB and the plastic mix asphalt, the same trend was obtained, which is that the bitumen content percentage has a direct relation to flow rate and stability.

3.3. Plastic Mix Asphalt Calculation

The experimental study for the calculation of the optimum bitumen binder is as per Table 4. The overall picture of Table 4 indicates that the addition of plastic to hot aggregate creates a coating of polymer on the aggregate surface. This coating reduces the gaps between two adjacent aggregates and also reduces the water absorption of the aggregates. As the empty spaces between the aggregates are reduced and less water is absorbed by the aggregates, this thus increases the strength of the roads and reduces the amount of hole formation in the roads [28]. The key advantage of this new technology is that it is environmentally friendly, in the sense that it does not harm the environment.

Table 4. Various test values of plastic mix asphalt specimen.

Bitumen Content (%)	Unit Wt. (gm/cm^3)	Void Mineral Aggregate	% Air Voids	Corr. Stability (N)	Flow (mm)
4.5	2.065	19.52	15.73	9500	0.66
5	2.072	18.28	13.98	11,856	0.87
5.5	2.08	18.41	13.67	9424	1.1
6	2.198	18.56	13.37	9165.6	1.25
6.5	2.095	18.69	13.03	6232	1.43

The optimum bitumen content for plastic mix asphalt is 5.833%.

Based on the above experiments conducted on the specimen in the laboratory, the optimum bitumen content (%) for standard bitumen, crumb rubber modified bitumen, and plastic-coated aggregate was found to be 6.166%, 6.6%, and 5.833%, respectively. Table 2 shows that, in the case of standard bitumen, increasing the bitumen content percentage increases the percentage of voids from mineral aggregates while decreasing the percentage of air voids, leading to a strong impact on the microstructure of the mixture. Hence, it increases the stability of standard bitumen with its flow rate, but only up to a certain limit, e.g., 6% of bitumen content.

By comparing the obtained results from the CRMB and PCA, it was observed that the direct proportion to stable properties does not remain constant. The tremendous properties of maximum stability were obtained for standard bitumen (6240 N), CRMB (7031 N), and PCA (11,856 N). It was also concluded that flow rate also varied within the three mixtures compared to the percentage of bitumen content, because all three mixtures had different microstructure properties that altered their viscosity coefficients. The common practice of "increasing the percentage of bitumen content has a direct relationship with flow ability" was observed in standard bitumen, CRMB, and PCA.

By referring to Table 4, it was observed that plastic coated aggregate has a higher stability value than the other two specimens, which states that the plastic mixed asphalt is the best among the three samples selected. Hence, our objective was proved, that plastics can be utilized for modifying and enhancing the mechanical properties of asphalt, with extra additional benefits related to economic gains, reduction in pollution, and development of a sustainable environment.

Recently, the disposal of indecomposable waste such as rubber waste and plastic waste has become a big problem. The major percentage of indecomposable waste consists of rubber and plastic and is disposed of in urban and rural areas. Several environmental problems, such as air pollution and aesthetic pollution, are caused by this indecomposable waste. This pollution, moreover, causes severe health-related issues. The solution to this problem is to utilize this waste for purposes which have economic benefits and increase recyclability, whereby they are utilized for their technical material strength.

In recent years, by-products of rubber waste and plastics have been used in road construction with great interest in many developing countries. It is possible to successfully address the pollution and disposal concerns associated with rubber and plastic waste if these waste by-products are used and their optimum percentages are applied according to the results given in highway road construction. Considering the bulk reuse of these wastes in under-developed countries, it was very important to examine these by-product materials to develop specifications to increase the use of rubber and plastic wastes in road making, and to produce as high of an economic return as possible.

Tested specimens of Marshall mix design areas Figures 2–4.

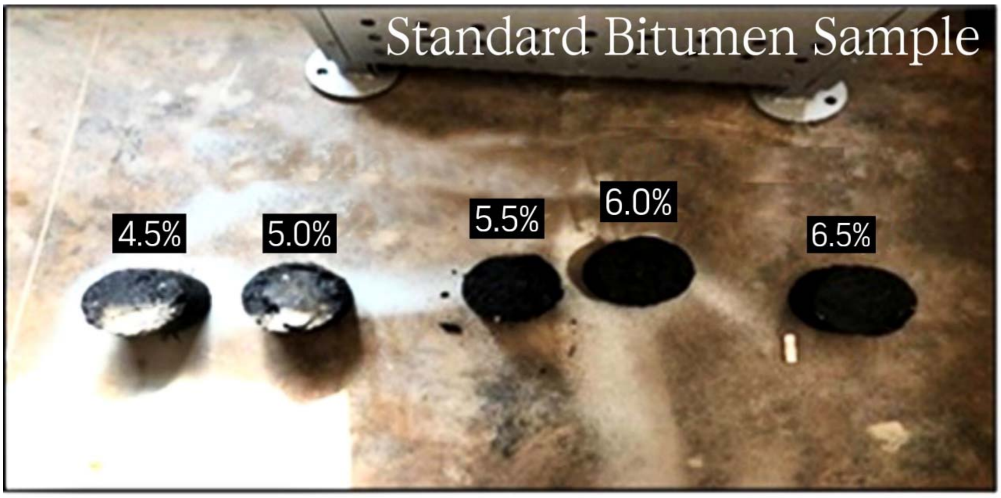

Figure 2. Tested specimen of standard bitumen.

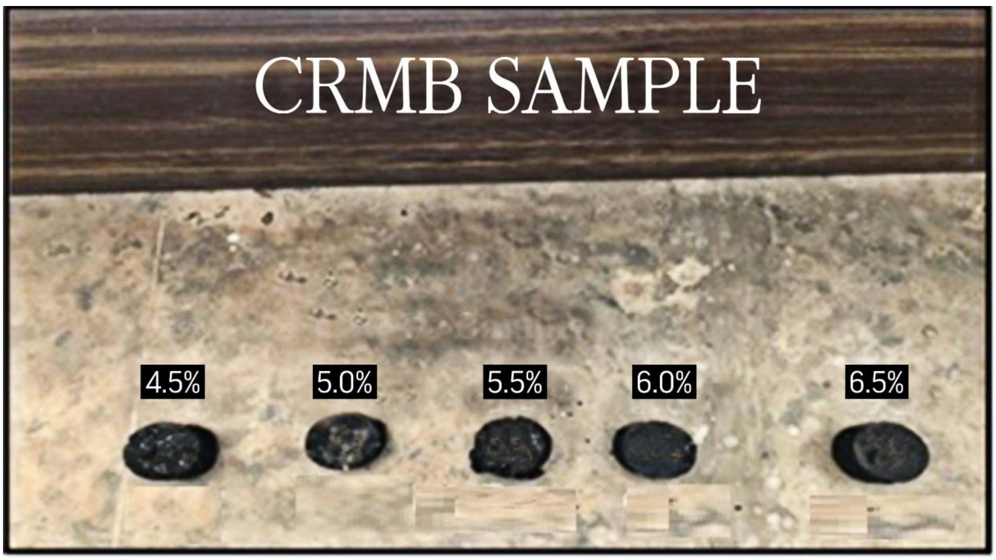

Figure 3. Tested specimen of CRMB.

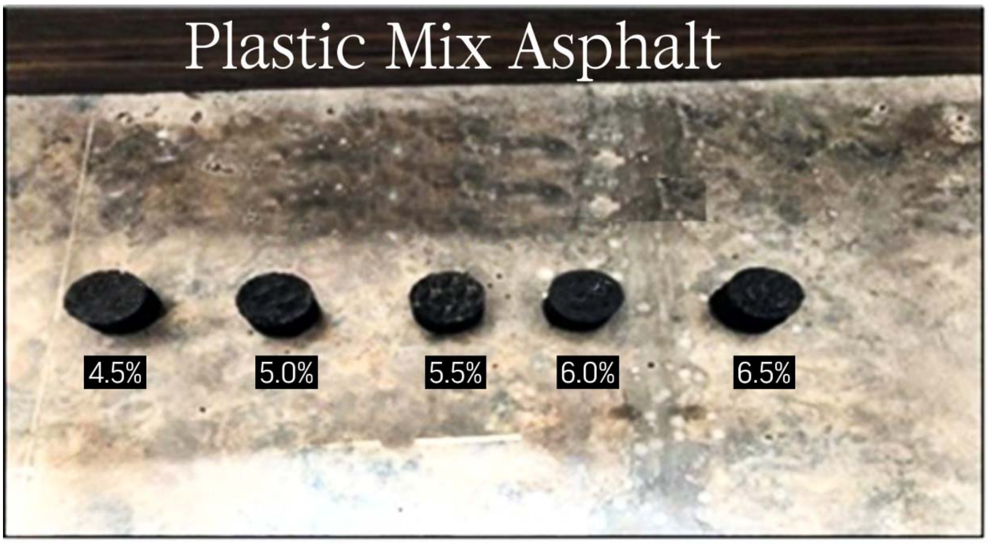

Figure 4. Tested specimen of plastic mix asphalt.

4. Conclusions

From the findings of the current study, the following conclusions were drawn:

Plastic mix asphalt has the maximum strength and least optimum bitumen content as compared to standard bitumen and crumb rubber modified bitumen. The cost of construction of pavements using CRMB is expensive as compared to standard bitumen and thus can be used only when it requires higher quality and cost is not a restriction. Maximum stability was obtained in standard bitumen with a bitumen content of 6.5% and a relatively high flow rate of 0.88 mm. Increased content percentage improved flow stability, but this trend did not continue for CRMB and plastic bitumen. In the CRMB calculation, maximum stability was found at 5.5% bitumen content with a flow of 3.05 mm. In the PCA results, the maximum flow rate was obtained with 6.5% bitumen content, whereas the maximum stability was obtained with 5% bitumen content. Hence, by using plastic, the reduction in cost and pollution, and sustainable development are additional benefits with the improved properties of bitumen. The roads formed via mixing plastic waste with bitumen and aggregate will have better performance as compared to normal asphalt roads, but proper mixture percentages are required before their employment.

Author Contributions: Conceptualization, A.K. and P.B.; methodology, A.I.A.-M.; validation, A.K., P.B. and M.A.K.; formal analysis, S.A.; investigation, S.M.L.; resources, A.M.; data curation, A.I.; writing—original draft preparation, A.K.; writing—review and editing, M.A.K.; funding acquisition, A.I.A.-M. All authors have read and agreed to the published version of the manuscript.

Funding: The authors would like to acknowledge the support provided by Researchers Supporting Project (RSP2022R424), King Saud University, Riyadh, Saudi Arabia.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: Researchers Supporting Project (RSP2022R424), KSU, Riyadh, Saudi Arabia.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Association of State Highway and Transportation Officials (AASHTO). *Standard Specifications for Transportation Materials and Methods of Sampling and Testing*; AASHTO: Washington, DC, USA, 1993.
2. American Society for Testing and Materials. *Annual Book of ASTM Standards Section 4*; ASTM-D1559-; American Society for Testing and Materials: Philadelphia, PA, USA, 2002.

3. Shen, J.; Li, B.; Xie, Z. Interaction between crumb rubber modifier (CRM) and asphalt binder in dry process. *Constr. Build. Mater.* **2017**, *149*, 202–206. [CrossRef]
4. Voskuilen, J.L.M. Causes of premature ravelling failure in porous asphalt. In Proceedings of the 6th RILEM Symposium PTEBM'03, Zurich, Switzerland, 14–16 April 2003; pp. 191–197.
5. Nimisha, P.R.; Muhammed Shahid, P.T.; Krishna Priya, K.U.; Mohammed, M.; Jobbi, R. Experimental studies on the properties of modified bituminous mixes using crumb rubber. *Int. Res. J. Eng. Technol.* **2018**, *5*, 8.
6. Dantas Neto, S.A. Evaluation of the Properties of Binders and Mixes Modified with Crumb Rubber from Used Tires. Ph.D. Thesis, University of Brasilia, Brasilia, Brazil, 2004. (In Portuguese).
7. Takallou, H.B.; Takallou, M.B. Effects of mixing time and temperature on the visco-elastic properties of asphalt rubber binder. *Asph. Rubber* **2003**, *12*, 589–602.
8. Anderson, J.; Pampulim, V.; Saim RSousa, J.B. Asphalt rubber laboratory properties related to type and process technology of crumb rubber. In Proceedings of the Asphalt-Rubber Congress, Lisbon, Portugal, 17–19 July 2000.
9. Bieliatynskyi, A.; Yang, S.; Pershakov, V.; Shao, M.; Ta, M. The use of fiber made from fly ash from power plants in China in road and airfield construction. *Constr. Build. Mater.* **2022**, *323*, 126537. [CrossRef]
10. Raju, Y.K.; Kumar, N.H. Strength Performance of Crumb Rubber Concrete. *Int. J. Res. Appl. Sci. Eng. Technol.* **2019**, *7*, 2007–2010. [CrossRef]
11. Vasudevan, R. A technique to dispose waste plastics in an ecofriendly way—Application in construction of flexible pavements. *Constr. Build. Mater.* **2012**, *28*, 311–320. [CrossRef]
12. Punith, V.S.; Veeraragavan, A. Behavior of Asphalt Concrete Mixtures with Reclaimed Polyethylene as Additive. *J. Mater. Civ. Eng.* **2007**, *19*, 500–507. [CrossRef]
13. Al-Hadidy, A.; Yi-Qiu, T. Effect of polyethylene on life of flexible pavements. *Constr. Build. Mater.* **2009**, *23*, 1456–1464. [CrossRef]
14. Makovetskaya-Abramova, O.; Iwanow, A.; Lazarev, Y.; Szachowa, M.; Rozov, A. Economic assessment of consruction of the roadside service facilities. *EDP Sci.* **2020**, *157*, 04035.
15. McQuillen, J.L.; Takallou, H.B.; Hicks, R.G.; Esch, D. Economic analysis of rubber-modified asphalt mixes. *J. Transp. Eng.* **1988**, *114*, 259–277. [CrossRef]
16. Ali, A.H.; Mashaan, N.S.; Karim, M.R. Investigations of Physical and Rheological Properties of Aged Rubberised Bitumen. *Adv. Mater. Sci. Eng.* **2013**, *2013*, 239036. [CrossRef]
17. Peralta, J.; Silva, H.; Machado, A.; Pais, J.; Pereira, P.; Sousa, J.B. Changes in Rubber Due to its Interaction with Bitumen when Producing Asphalt Rubber. *Road Mater. Pavement Des.* **2010**, *11*, 1009–1031. [CrossRef]
18. Vonk, W.C.; Bull, A.L. Phase phenomena and concentration effects in blends of bitumen and cariflex TR. In Proceedings of the 7th International Roofing Congress, Munich, Germany, 12–14 June 1989.
19. Sun, D.Q.; Li, L.H. Factors Affecting the Viscosity of Crumb Rubber–Modified Asphalt. *Pet. Sci. Technol.* **2010**, *28*, 1555–1566. [CrossRef]
20. *IS 1203:1978*; Bitumen and Bituminous Binders. Determination of Needle Penetration. Indian Standards Institution: New Delhi, India, 1978.
21. *IS 1205-1978*; Bitumen and Bituminous Binders. Determination of Softening Point. Ring and Ball Method. Indian Standards Institution: New Delhi, India, 1978.
22. *IS 1208-1978*; Determination of Ductility of Bitumen Water Bath Method. Indian Standards Institution: New Delhi, India, 1978.
23. *IS 1202-1978*; Specific Gravity Test. Indian Standards Institution: New Delhi, India, 1978.
24. *IS 1206-1978*; Determination of Viscosity of Bitumen Using Viscometer. Indian Standards Institution: New Delhi, India, 1978.
25. *IS 1209-1978*; Determination of Flash and Fire Point Using Pensky-Martens Flash Point Apparatus. Indian Standards Institution: New Delhi, India, 1978.
26. Brown, E.R.; Kandhal, P.S.; Zhang, J. Performance testing for hot mix asphalt. In *NCAT Report 01-05*; 277 Technology Parkway Auburn University: Auburn, AL, USA, 2001.
27. Al-Busaltan, S.; Al Nageim, H.; Atherton, W.; Sharples, G. Green Bituminous Asphalt relevant for highway and airfield pavement. *Constr. Build. Mater.* **2012**, *31*, 243–250. [CrossRef]
28. Singh, V.; Bawa, A. Experimental study on partial replacement of bitumen with crumb rubber. *SSRG Int. J. Civ. Eng.-Spec.* **2017**, 9–14.