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Performance assessment of sustainable pavement including glass waste powder

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ABSTRACT

Flexible pavement will deteriorate with time and sever distresses will appear because of many factors that might influence its surface particularly in terms of performance and serviceability. For example, excessive traffic loads, variation in temperatures, mistakes in job mix design and poor maintenance. Therefore, three main roads in Samawah city were investigated to evaluate their surface conditions by determining the present serviceability index (PSI). The roads were classified as poor and fair based on surface conditions. Following that, an improvement strategy of production of sustainable mixture was suggested by integrating a certain percentage of glass powder (5-15%) as a part of fine particles content. The modified mixture was tested and compared to the reference mixture in terms of Marshall properties and rutting behavior. With a 10% glass powder added, the findings showed that stability improved by 30% compared to the controlled mixture. On the other hand, flow and air voids content increased as the glass powder content increased. Rutting deformation presented an increasing trend as the content of glass powder increases. Finally, the sustainable mixture met the Iraqi SORB/R9 standards.

Keywords: Glass powder; Marshall tests; Present serviceability index; Rutting performance.

1. INTRODUCTION

In recent decades, sustainable road construction practices emphasize on integration of waste-derived materials into hot mix asphalt (HMA). Considerable interest in the use of recycled materials (e.g., plastics (Al-Tuwayyij et al., 2025), tier rubber (Musa et al., 2024), concrete aggregates (Musa et al., 2021), modified asphalt (Ali et al., 2022) has taken insight because such materials can provide a good lifespan of pavement under varied reverse conditions. Among these materials, glass waste powder (GWP) has shown a promising building material in HMA because of its pozzolanic characteristics and abundance as well as its ability to improve performance properties of bituminous mixtures. Annually, over 10 million tons of glass waste has been generated around the world. Glass waste recycling not only eliminates landfill areas but also reduces the need for natural aggregates and fillers.

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Roughly, glass waste is mostly composed of silica (SiO_2), as shown in Figure 1. Also, it has amorphous structure in addition to high hardness. As a result, it is a suitable material that can be applied for improving asphalt mixture performance. It can be used either as a mineral filler or as partial aggregate replacement. Cheng et al., (2021) presented the morphology of glass waste mixture and indicated that particle size distribution and surface properties might increase skid resistance compared to traditional mineral fillers. However, the angular shape of glass particles may influence mixture characteristics such as compaction and workability, requiring proper gradation control according to Hamada et al., (2022). This may affect road surface quality under extreme climate conditions and heavy traffic loads due to social, business and economic activities. Aging and mismanagement of roads also lead to deterioration and different types of cracking. Thereby, great attention must be paid to maintenance and preservation.

Furthermore, numerous studies have investigated the mechanical and durability implications of integrating GWP into HMA. Abu Salem et al., (2017) indicated that Marshall stability and resistance to moisture damage were improved after replacing (10–15%) of conventional filler with GWP. This is likely due to high silica content that enhanced adhesion between glass particles and binder. Moreover, similar results were obtained after assessing surface mixtures containing GWP. The researchers Anochie-Boateng and George (2016), Asthana et al., (2020), Barraj et al., (2023) and Khedaywi et al., (2024) reported that the indirect tensile strength and rutting resistance were increased at a certain level of GWP replacement in the HMA. They demonstrated that extra increases further than this threshold may lead to stiffness and cracking concerns. On the other hand, Saltan et al., (2015) revealed that GWP content tends to decrease air voids and increase the voids in mineral aggregate, indicating a potential improvement in the durability of asphalt concrete under cyclic loading circumstances. Under repeated traffic loading conditions, fatigue life showed a significant improvement with GWP content (10-15%) in the HMA, as observed in studies performing indirect tensile fatigue test. Barraj et al., (2023) indicated that adding GWP as filler (by 25%) could improve thermal and fatigue cracking compared to the reference HMA. However, rutting behaviour was developed but remained within the accepted limit. The researchers Arabani et al., (2012), Kalampokis et al., (2023) and Xing et al., (2019) explained that excessive contents of GWP in the mix reduced stiffness and increased brittleness.

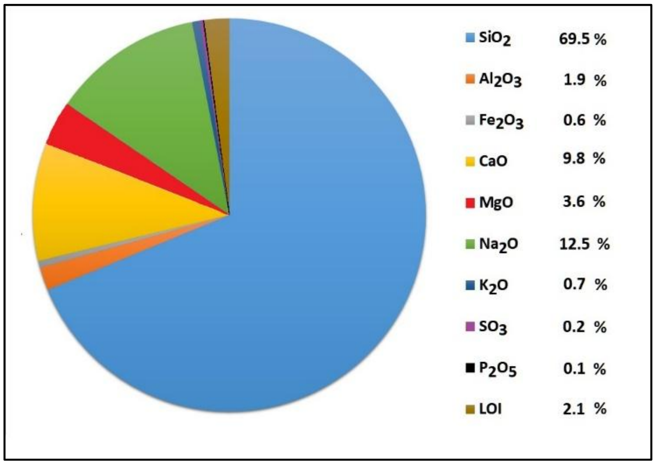

Figure 1. The chemical composition of glass waste (created by authors according to Hamada et al., (2022)).

Finally, the objective of the current study is to assess road surface conditions in Samawah city by evaluating various observed distresses on selected main roads. The assessment guidelines will be subsequently useful for road experts for maintenance of roads and suggested effective solutions will be drawn. Following that, a sustainable asphalt mixture will be prepared (by replacing 5%, 10% and 15% of fine particles less than 0.075 mm with GWP) and examined via Marshall and resistance to rutting tests.

2. MATERIALS AND METHODS

2.1. Evaluation of study sites

To achieve the objectives of this study, three main roads were visited for evaluation in Samawah city (the capital of Al-Muthanna province) as shown in Table 1. Basically, these roads serve residency, industry and business areas. The measurements were taken manually as using the measuring tape to record the lengths and widths of the detected distress areas as illustrated in Figure 2. The practical work was conducted in September 2025 under prevailing traffic and weather conditions. As a result, estimation of traffic loads is based on route planning that involves a prediction of future increase of population and economical activities. In addition, the effect of land use should be taken into consideration to estimate potential alternatives of transport.

Table 1. Roads Description in the survey site

Road title	Traffic direction	Legal speed (kph)	Area of studied section (m^2)
Al-Doha main road	Two-way, three-lanes	80	25×40
Al-Maeali main road	Two-way, two-lanes	60	30×34
Al-Taqa main road	Two-way, three-lanes	100	30×33

a- Field measurement of Al-Doha main road

b- Field measurement of Al-Maeali main road

c- Field measurement of Al-Taqa main road

Figure 2. Field measurements of three main roads in Samawah city

The development plans of existing road network are orderly including continuous processes of evaluation and maintenance to keep road systems in good conditions. However, high temperatures, long-term of summer and lack quality control of asphalt mixture have affected road surface maintenance in recent years. Also, high traffic demand has affected significantly on increasing pavement distresses.

To evaluate pavement conditions, the concept of serviceability performance was employed. A procedure was developed to determine the Present Serviceability Index (PSI) of the pavement, based on its roughness and distress, which were observed and measured in terms of extent of cracking, rutting and patching in the flexible pavements. According to AASHTO (2022), the rating scale of PSI ranges from 0 to 5 as shown in Figure 3.

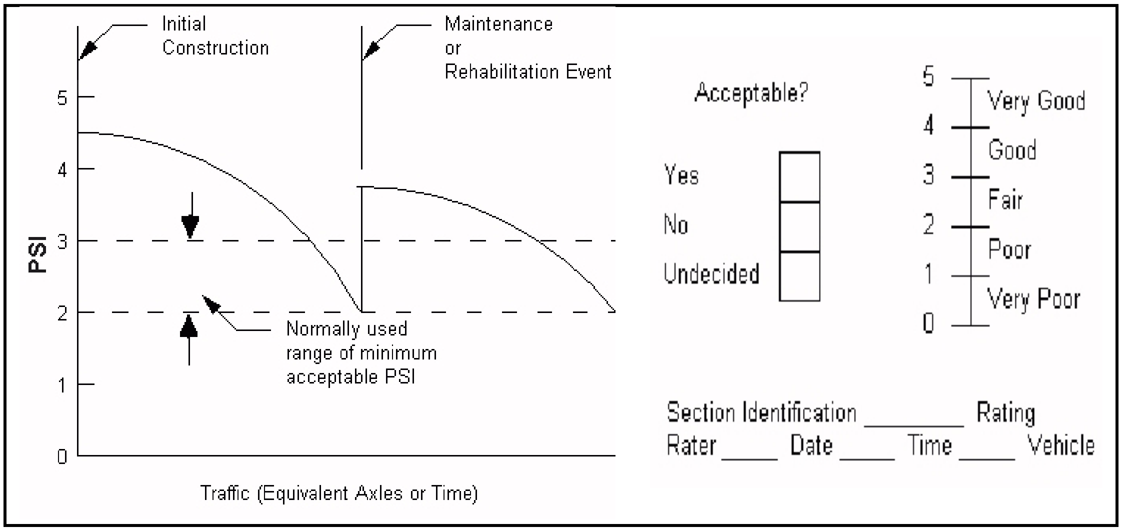

Figure 3. Present Serviceability Index (PSI) Scale

The PSI of flexible road section can be represented mathematically by the following equation:

$$PSI = 5.03 - 1.91 \log_{10}(1 + SV) - 1.38 \times RD^2 - \frac{(C+P)^{1/2}}{100} \qquad \ldots\ldots\ldots\ldots\ldots (1)$$

Where,
SV: Slope variance (inch)
RD: Rut depth (inch)
C & P: Cracking and Patching area (ft^2 /1000 ft^2 of pavement area)

The rating scale of PSI should be in the range between 0 and 5 as mentioned previously. Before performing a safe site examination, the first step was led by the visual inspection team for recognizing defects in the surface. The defective surface areas of pavement were observed, and landmarks were made for later measurements. The collected data included identification of each type of distress and computed the area of distress. Also, slope variance was measured by using a profilometer. The collected data may help engineers in making decisions regarding the rehabilitation process. The calculations of the reported areas can be presented in Table 2.

Table 2. Field measurements of pavement distress data for three main roads

Road title	**Al-Doha main road**		**Al-Maeali main road**		**Al-Taqa main road**	
Marked section	**1**	**2**	**1**	**2**	**1**	**2**
Longitudinal cracks (ft)	17.75	45.33	133.66	112.75	133.66	49.75
Fatigue cracks (ft^2)	16.825	121.72	222.44	221.25	87.50	139.14
Transvers cracks (ft)	10.03	35.83	10.12	10.07	10.01	36.50
Rutting (inch)	1.35	1.45	1.35	1.55	1.65	1.65
Patching (ft^2/1000 ft^2)	10.76	82.57	8.66	5.37	6.29	77.58
Slope variance (inch)	1.38	2.11	1.52	1.73	2.42	1.87
PSI value	1.721	1.018	1.555	0.695	0.099	0.224
Average PSI	**1.370**		**1.125**		**0.163**	
Pavement condition	**Poor**		**Poor**		**Very poor**	

Based on the observed defected areas and PSI values, the overall road surface conditions of the studied sites were set on (Poor) and (Very poor). These results reflect the significant impacts of traffic loads and varied climate temperature on the road surface. As well, it is worth noting that the prepared HMA should meet the requirements of Iraqi specifications for road and bridges (SORB/R9) regarding with surface mixtures (Jabor and Azawi, 2014).

2.2. Preparation of asphalt mixtures

2.2.1. Materials

Four materials were used for preparing controlled and modified asphalt concretes. All materials are available in Iraq, and it can be listed as follows:

1. *Asphalt type:* A binder of 40/50 penetration grade was used in the existing study that manufactured in Al-Samawah refinery. The physical characteristics of the asphalt 40/50 grade can be shown in Table 3.

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Table 3. Laboratory tests of Asphalt 40/50

Laboratory tests	Units	Asphalt 40/50	Specification
Penetration 100 gm at 25°C & 5 sec	1/10 mm	42	ASTM D5
Absolute Viscosity at 60°C	Poise	3255	ASTM D88
Kinematic Viscosity at 135°C	C st	405	ASTM D88
Ductility at 25°C & 5 cm/min	cm	145	ASTM D113
Softening Point (Ring & Ball)	°C	49.1	ASTM D36
Specific Gravity at 25°C	-	1.06	ASTM D70
Flash Point (Cleveland Open Cup)	°C	306	ASTM D92

2. *Natural aggregates:* These materials were selected from Karbala quarry. Aggregates were washed and sieved into different sizes. Tables 4 and 5 present the physical characteristics of fine and coarse aggregates, respectively. Following that, the sieved aggregates will be mixed with filler to meet the requirements of Iraqi specification SORB/R9 (Jabor and Azawi, 2014) of surface layer type III.B as shown in Table 6.

3. *Filler material:* Ordinary Portland cement was used as filler material in the current work. It was collected from the Samawah factory. The physical characteristics can be presented in Table 7.

4. *Glass powder:* This can be collected from local factories that deal with recycling of vehicles windshields involving accidents after separation Polyvinyl Butyral (PVB) plastic interlayer. Washing process is usually employed before mechanical crashing and sieving into different sizes. Glass particle sizes less than 200 mm were used in the experiments. In the current study, glass powder was used as a partial replacement of filler with 5%, 10%, and 15% by weight following the SORB/R9 (Jabor and Azawi, 2014) recommended limits. The chemical composition of selected glass powder can be presented in Figure 4.

Table 4. Physical properties of natural fine aggregates

Property	Units	Results	Specification
Bulk specific gravity	-	2.65	ASTM C127-88
Bulk SSD specific gravity	-	2.62	ASTM C127-88
Apparent specific gravity	-	2.66	ASTM C127-88
Absorption	%	1.24	ASTM C127-88
Air voids	%	47.3	ASTM C1252-23

Table 5. Physical properties of natural coarse aggregates

Property	Units	Results	Specification
Bulk specific gravity	-	2.64	ASTM C127-88
Bulk SSD specific gravity	-	2.63	ASTM C127-88
Apparent specific gravity	-	2.68	ASTM C127-88
Absorption	%	1.1 %	ASTM C127-88

Fractured particles	%	94% (Min 90%)	ASTM D5821-3
Resistance to abrasion (Los-Angeles machine)	%	20% (Max 30%)	ASTM C131

Table 6. Gradation of mixed aggregates for preparing bituminous surface layer (Type III.B) (Jabor and Azawi, 2014)

Sieve size (mm)	**12.5**	**9.5**	**4.75**	**2.36**	**0.3**	**0.075**
Allowable percentages (%)	100	90-100	55-85	32-67	7-23	4-10
Percentage of passing (%)	100	95	72	45	12	5

Table 7. Physical properties of ordinary Portland cement

Properties	**Results**	**Specification**
% Passing Sieve No. 200	100%	ASTM C117
Liquid limit (L.L %)	25%	SORB/R9
Plasticity index (P.I %)	3.4%	SORB/ R9

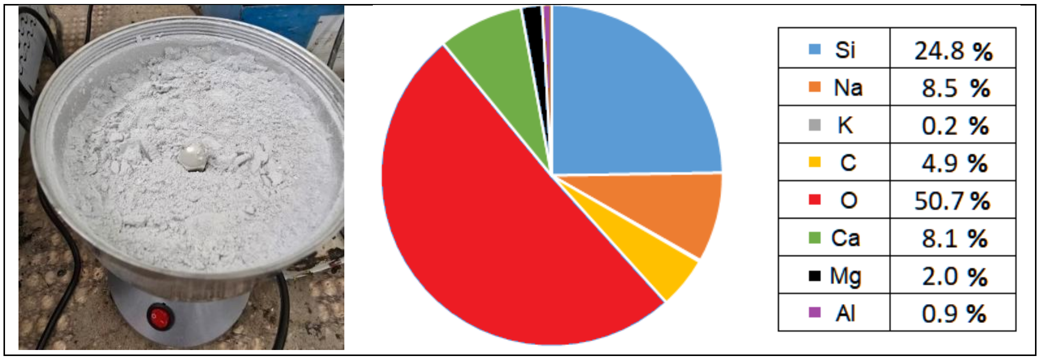

Figure 4. Chemical components of vehicles windshields glass powder

2.3. Laboratory Works

Two mixtures were utilized in the existing work. The first is a controlled mixture with 0% GWP, and the second is a modified mixture that contains a specific amount of GWP. In both mixtures, the procedures of ASTM D6926 were adopted and implemented for mixing conditions at temperature of 160^{o}C. In addition, median limits within the recommended aggregate gradation of surface layer type III.B (Table 7) were mixed with asphalt 40/50 to prepare asphaltic specimens of 1200 gm (in approximate). The binder content varied as 4%, 4.5%, 5%, 5.5% and 6%. To obtain the optimum bitumen content (OBC) from Marshall tests, the compacted specimens will be examined at 135^{o}C using the standard Marshall apparatus to find out the volumetric characteristics as recommended by SORB/R9 (Jabor and Azawi, 2014). Then, the calculated OBC can be found as follows based on previous works:

$$OBC = \frac{BC_{Smax} + BC_{BD} + BC_{AV}}{3} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where,

BC_{Smax}: recorded bitumen content at maximum stability.

BC_{BD}: recorded bitumen content at maximum bulk density.

BC_{AV}: recorded bitumen content at 4% air voids in total mixture.

On the other hand, three types of modified mixtures were prepared (based on obtained OBC) and included three different glass waste powder contents (i.e., 5%, 10% and 15%). The certain amount of GWP was used as a partial replacement of fine particles that passed sieve No.200 (0.075 mm). Accordingly, the modified specimens were compacted and examined using the standard Marshall apparatus to find out maximum stability, bulk density and air voids as recommended by SORB/R9 (Jabor and Azawi, 2014). The results of modified samples will be compared with those of controlled mixture as described in the next section.

Following Marshall tests, additional compacted slabs (dimensions of 40 cm diameter and 5 cm thickness) were collected from the controlled and modified mixtures and prepared for evaluating rutting performance due to traffic loads. Rutting depth can be determined by applying repeated compressive loads after placing the compacted slab in an oven at specific temperatures 40°C and 60°C for 4 hours. Then, the compacted slabs will be placed in the Hamburg wheel track device (AASHTO, 2013) and loads of 705 ± 4.5 N will be applied from a rolling wheel of 40 cycle/min velocity for total 20,000 passes. The rutting depth will be recorded before achieving 20 mm deformation.

3. RESULT AND DISCUSSION

3.1. Marshall Tests

The main objective of this paper was to study modification of asphalt mixture properties by replacing a certain amount of filler material with glass powder obtained from crushed cars windshields. In the beginning, the prepared samples of controlled mixture were examined in the Marshall apparatus to determine the optimum content of asphalt 40/50. Finally, the OBC was achieved at 4.94% for the base mixture as shown in Figure 5.

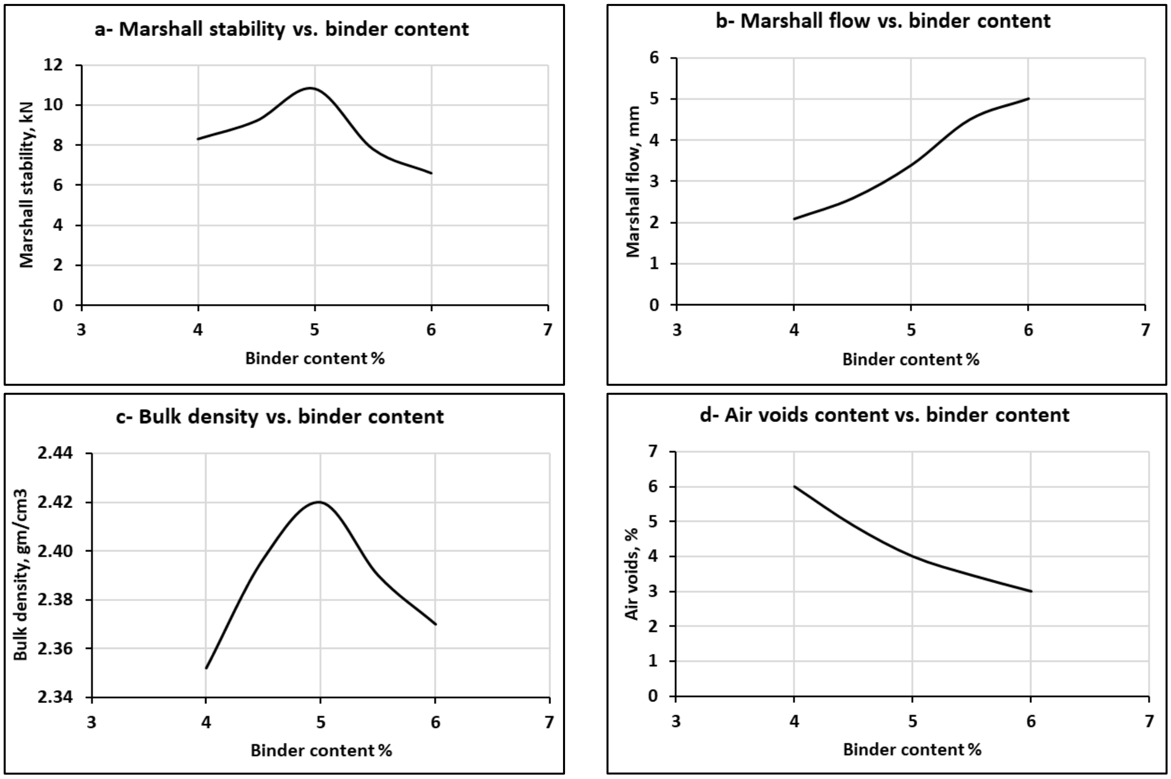

Figure 5. Results of Marshall tests for the controlled mixture

As mentioned previously, similar experimental tests were carried out using the standard Marshall apparatus to examine performance of compacted specimens of modified mixture with 5%, 10% and 15% GWP. Marshall stability, flow and air voids of the compacted samples were recorded (based on the OBC) and the results were compared with the results of base mixture (i.e., 0% GWP) (Figure 6). According to the SORB/R9 (Jabor and Azawi, 2014), minimum Marshall stability of surface layer type III.B should not be less than 8 kN. As shown in Figure 6a, the recorded stability values for both mixtures were higher than the required limit. The maximum stability was reported at 13.78 kN after adding 10% GWP, indicating that Marshall stability of modified mixture increased by 30% compared to the controlled mixture.

In addition, Marshall flow values were reported within the acceptable range (2-4 mm) as recommended by the Iraqi SORB/R9 (Jabor and Azawi, 2014). As illustrated in Figure 6b, Marshall flow showed dramatic decreases of 32%, 26% and 17% after replacing 5%, 10% and 15% of fine particles with GWP, respectively; compared to the controlled mix. Also, the percentages of voids in total mixture (VTM) increased gradually as the amount of GWP increased as illustrated in Figure 6c. According to the Iraqi SORB/R9, the obtained

VTM precents were within the acceptable range (3%-5%). Consequently, replacing fine particles more than 5% might increase the amount of VTM. This result was comparable to Al-Saffar (2013) findings who stated that the percentage of VTM increased as the glass powder content increased. Similarly, the content of voids in mineral aggregate (VMA) increased gradually as GWP% increased as shown in Figure 6d. The recommended percentage should be greater than 14% based on SORB/R9 (Jabor and Azawi, 2014). There was 23.5% increase in the amount of VMA% after using 15% GWP in the mixture compared to the original percent in the base mixture. This increase was also noted by Al-Saffar (2013) in his experimental works.

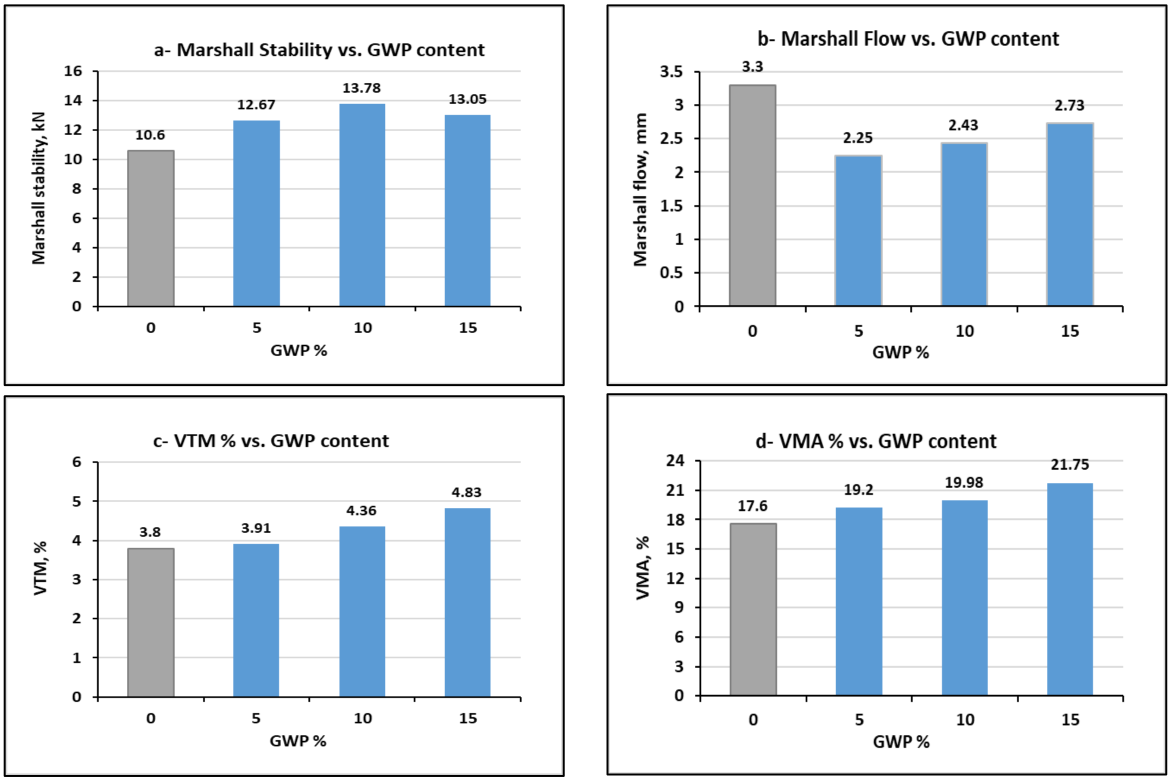

Figure 6. Results of Marshall tests for the controlled and modified mixtures

To conclude, it can be mentioned that the obtained results of modified mixtures showed good agreement with the requirements of SORB/R9 (Jabor and Azawi, 2014) as shown in Table 8. Adding a specific amount of glass waste powder as a partial replacement of fine particles (less than 0.075 mm) showed a significant enhancement in the mixture performance compared to the conventional mixture, particularly in terms of resistance to plastic flow.

Table 8. Summary of controlled and modified asphalt concrete before and after adding GWP%

Marshall properties	**Controlled mixture (0% GWP)**	**Modified mixture with GWP%**			**Iraqi SORB/R9 for surface layer** (Jabor and Azawi, 2014)
		5%	10%	15%	
Optimum asphalt content (OAC%)	4.94	4.94	4.94	4.94	4.0 – 6.0
Marshall stability, kN	10.6	12.67	13.78	13.05	Min 8.0
Marshall flow, mm	3.3	2.25	2.43	2.73	2.0 – 4.0
Air voids in total mixture (VTM%)	3.8	3.91	4.36	4.83	3.0 – 5.0
Voids in mineral aggregate (VMA%)	17.6	19.2	19.98	21.75	Min 14

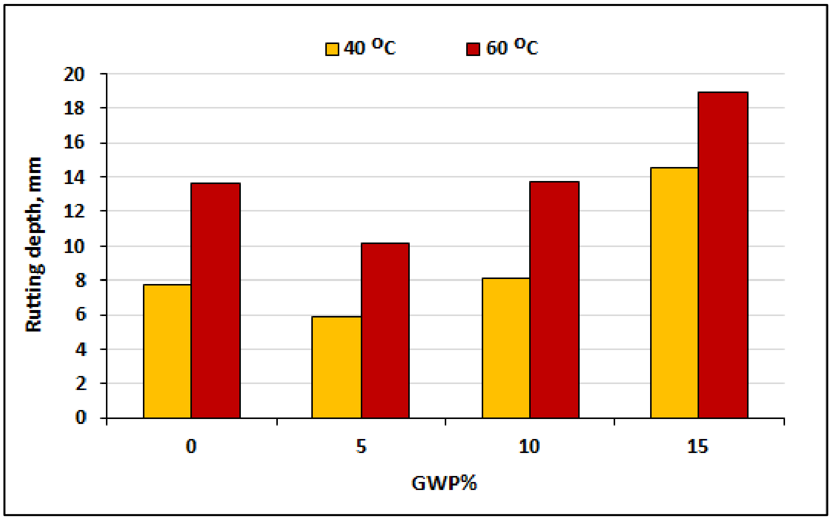

Figure 7. Results of rutting deformation at simulated temperatures of 40°C and 60°C

3.2. Measurement of rutting depth

Cylindrical slabs (40 cm diameter and 5 cm thickness) of controlled and modified mixtures were compacted and tested in the Hamburg wheel track device (AASHTO, 2013) for measuring the rutting deformation. The applied loads simulate the traffic axle loads under Iraqi summer season temperature of 40°C and 60°C. After 4 hours, the rutting depths of the compacted slab under controlled conditions (that mentioned previously) were recorded. As depicted in Figure 7, the rutting depth decreased significantly where a certain percentage of filler was replaced with 5% of glass waste powder. This fact can be explained that using glass powder as a part of filler material might enhance the workability of mixture and reduce the flow (Table 8). However, the rutting deformation developed as the amount of GWP increased that indicating the increase trends of flow and air voids. Also, the recorded depths at 40°C were less than those recorded at temperature of 60°C. The reported results were accepted and did not exceed the maximum limit of 2 cm based on Iraqi SORB/R9 (Jabor and Azawi, 2014) design requirements for surface layer.

4. CONCLUSION AND RECOMMENDATION

In the current study, three main roads were evaluated to assign PSI and road surface conditions. All roads had poor and fair marks due to observed distresses based on the calculated PSI values. Because of heavy traffic loads and absence of mix design control, this work aims to produce sustainable asphalt concrete containing glass powder as a partial replacement for fine particles (filler). For saving costs and achieving management system, glass powder is very cheap and can be obtained from different waste sources such as crushed bottles, car windshields and broken windows. It is worth mentioning that incorporation of glass powder in asphalt mixtures provides several advantages such as increases stability, resistance to rutting behavior and reduces landfill waste. Two asphalt concrete were prepared in this study. The first was base or reference mixture with 0% GWP, and the second was sustainable modified mixture with different GWP contents (5%, 10% and 15%) as a partial replacement of fine particles. As presented in the results, the sustainable mixture met the requirements of Iraqi SORB/R9 in terms of Marshall properties and rutting performance. In comparison to the controlled mixture, Marshall stability and voids contents developed as GWP% increases. Whereas reduction trend was observed on Marshall flow. This can be indicated that the added content of glass powder should remain within the allowable limits of SORB/R9, however any extra content might air voids and result in unworkable and brittle mixture. Finally, it is recommended to implement this practice in road maintenance plans in regions with similar extreme temperatures and traffic loads conditions.

For future research, it is necessary to recommend adding crushed glass as a partial replacement of fine aggregate (greater than 0.075 mm size, for example, materials retained on sieve No. 50) since its texture, hardness, and angular shape can improve the skid resistance and friction between tires and road surface, particularly in wet conditions. Also, using a mix of glass powder and other filler materials (such as silica fumes, limestone, and fly ash) can enhance the workability of asphalt concrete and its resistance to deformation under heavy traffic loads.

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Author Contributions

Conceptualization, Supervision and Writing—original draft preparation, N.A. (Noorance Al-Mukaram); Methodology and Formal analysis, S.S.M. (Sarah Safaaldeen Musa); Investigation and Resources, S.S.M. (Sarah Safaaldeen Musa); Data curation and Formal analysis, H.A. (Husham Al-Tuwayyij); Visualization and Writing—review and editing, H.A. (Husham Al-Tuwayyij).

Ethical issues

Not applicable. This study does not involve any experiments on humans or animals. Hence, ethical approval was not required.

Informed consent

Not applicable.

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Conflict of Interest

The authors declare that they have no conflicts of interest, competing financial interests or personal relationships that could have influenced the work reported in this paper.

Data and materials availability

Data that support the findings of this study are embedded within the manuscript.

REFERENCES

1. AASHTO. Road Tests. Department of Transportation. Federal Highway Administration; 2022. (FHWA Highway History Website Articles). https://rosap.ntl.bts.gov/view/dot/68620
2. AASHTO. T-324: Hamburg Wheel-Track Testing of compacted Hot Mix Asphalt (HMA). Washington, DC, USA.: American Association of State Highway and Transportation Officials; 2013.
3. Abu Salem Z, Khedawi T, Baker M, Abendeh R. Effect of Waste Glass on Properties of Asphalt Concrete Mixtures. Jordan J Civil Eng 2017;11(1).
4. Ali AM, Al-Mukaram N, Lafta AM. The properties of asphalt modified with waste vegetable oil. In. Samawah, Iraq. 2022;040027. doi:10.1063/5.0162986
5. Al-Saffar N. The effect of filler type and content on hot asphalt concrete mixtures properties. J Al-Rafidain Eng 2013;21(6):88–100.
6. Al-Tuwayyij H, Al-Mukaram N, Ali AM. The Role of Recycled Plastic Bottles in Enhancing Asphalt Longevity. Civ Eng J 2025;11(11):4587–601. doi:10.28991/CEJ-2025-011-11-09
7. Anochie-Boateng J, George T. Use of Waste Crushed Glass for the Production of Hot-Mix Asphalt. In. Las Vegas, USA. 2016;573–82. doi:10.18552/2016/SCMT4S198
8. Arabani M, Mirabdolazimi SM, Ferdowsi B. Modeling the fatigue behaviors of glasphalt mixtures. Scientia Iranica 2012;19(3):341–5. doi:10.1016/j.scient.2012.02.021
9. Asthana G, Choudhary J, Kumar B, Gupta A. Experimental Investigation of Waste Glass Powder as Filler in Asphalt Concrete Mixes. In: Kalamdhad AS, editor. Recent Developments in Waste Management [Internet]. Singapore: Springer Singapore. 2020;261–70. doi:10.1007/978-981-15-0990-2_20
10. Barraj F, Mahfouz S, Kassem H, Khatib J, Goulias D, Elkordi A. Investigation of Using Crushed Glass Waste as Filler Replacement in Hot Asphalt Mixtures. Sustainability 2023;15(3):2241. doi:10.3390/su15032241
11. Cheng M, Chen M, Wu S, Yang T, Zhang J, Zhao Y. Effect of waste glass aggregate on performance of asphalt micro-surfacing. Const Build Mat 2021;307:125133. doi: 10.1016/j.conbuildmat.2021.125133

12. Hamada H, Alattar A, Tayeh B, Yahaya F, Thomas B. Effect of recycled waste glass on the properties of high-performance concrete: A critical review. Case Stud Const Mat 2022;17:e01149. doi:10.1016/j.cscm.2022.e01149
13. Jabor Z, Azawi E. Hot Mix Asphalt Concrete Pavement. In: Specifications of Roads and Bridges (SORB/R9), Part One: Road Works. Baghdad - Iraq: Ministry of Construction and Housing. 2014.
14. Kalampokis S, Kalama D, Kesikidou F, Stefanidou M, Manthos E. Assessment of Waste Glass Incorporation in Asphalt Concrete for Surface Layer Construction. Materials 2023;16(14):4938. doi:10.3390/ma16144938
15. Khedaywi T, Haddad M, Khaldi NAH. Study on the feasibility of using waste glass in binder and asphalt mixture. Innov Infrastruct Solut 2024;9(6):227. doi:10.1007/s41062-024-01537-y
16. Musa SS, Al-Mukaram N, Dakhil IH. Asphalt binder modified with recycled tyre rubber. Open Eng 2024;14(1):20220495. doi:10.1515/eng-2022-0495
17. Musa SS, Al-Mukaram N, Mahdi MB. Assessment of Asphalt Mixture Behaviour Containing Recycled Concrete Aggregates. KEM 2021;895:139–46. doi: 10.4028/www.scientific.net/KEM.895.139
18. Saltan M, Öksüz B, Uz VE. Use of glass waste as mineral filler in hot mix asphalt. Sci Eng Composite Mater 2015;22(3):271–7. doi:10.1515/secm-2013-0135
19. Xing B, Fan W, Zhuang C, Qian C, Lv X. Effects of the morphological characteristics of mineral powder fillers on the rheological properties of asphalt mastics at high and medium temperatures. Powder Technol 2019;348:33–42. doi: 10.1016/j.powtec.2019.03.014