Assessing the Influence of Brick Powder as Filler in Asphalt Hot Mixes

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ABSTRACT

This study investigated the efficacy of utilizing waste Brick Powder (BP) as a partial or complete replacement for the filler in Hot Asphalt Mixes (HAM). BP was used to substitute Portland Cement (PC) in varying proportions: 25%, 50%, 75%, and 100%. The mixes were evaluated based on Marshall properties, Indirect Tensile Strength (ITS), and Tensile Strength Ratio (TSR). The findings revealed increased Marshall stability, stiffness, and ITS in the mixes containing BP. The flow decreased for HAM containing BP, particularly for those with a complete replacement of cement having utilized BP as the filler, indicating an improved ability of the HAM to withstand loads. The tests conducted at 25, 40, and 60 °C showed that the ITS increased steadily with an increased BP proportion, which is beneficial for rutting resistance, as high service temperatures influence rutting, and high ITS corresponds to a longer rutting life of the asphalt mix. The effect of improving the tensile strength at 60 °C was higher than at 25 °C and 40 °C. Additionally, the BP mixes demonstrated greater resilience to moisture effects compared to the reference mix. The use of BP as an alternative filler for PC did not significantly impact the volumetric properties of the HAM. It was determined that BP could be successfully added to the HAM at a 100% replacement rate as a filler, with an ideal asphalt content of 5.6%. The results suggest that the processing and management of waste bricks can be a sustainable development strategy.

Keywords-brick powder; filler; hot mix asphalt; Marshall properties; indirect tensile strength; moisture susceptibility

I. INTRODUCTION

The increasing generation of solid waste, particularly construction and demolition debris, poses a significant issue that requires effective management and treatment strategies to be deployed . This is due to the substantial environmental impact stemming from the limited capacity of landfills and the adverse health consequences, as well as the heightened energy consumption involved in transporting these materials or manufacturing replacements. Additionally, the provision of raw materials for construction and building processes significantly influences the economic well-being of societies [1]. In the industry of road construction, such waste materials have already been incorporated into pavement structure layers, such as the subbase and base layers [2, 3]. However, the utilization of these materials in the surface layer of asphalt pavement is currently restricted, necessitating further investigation and research. The composition of demolition-derived materials can vary across different regions, with concrete and bricks typically constituting the majority, while other components, including metals, soil, glass, wood, ceramics, and polymers, are also present [4-6].

In asphalt mixtures employed for paving applications, the inclusion of an appropriate amount of filler, typically comprising 5-10% of the total weight, is necessary to achieve the desired strength and density characteristics. The primary role of filler particles in the asphalt mix is to occupy the interstitial spaces between the coarse and fine aggregate particles, thereby enhancing the overall density and mechanical strength of the asphalt mixture [7-12].

PC, a prevalent ingredient in HAM, is not considered environmentally sustainable due to the excessive consumption of natural resources and significant greenhouse gas emissions associated with its production. The manufacture of one ton of cement results in the release of approximately one ton of carbon dioxide (CO_2). Consequently, to mitigate the environmental impact of PC, alternative materials must be explored [13]. In response to the global call for sustainable development, the concrete industry must utilize supplementary cementitious materials as substitutes for cement. One such alternative is the utilization of crushed clay bricks derived from construction and demolition waste, which has been shown to reduce environmental pollution and enable the development of sustainable hot asphalt mixtures in Iraq.

The crushed clay brick waste (SiO2, Al2O3, and Fe2O3) comprises more than 70% of the material, and is therefore classifyied as an active pozzolan [14]. Moreover, clay brick waste contains approximately 50% silica, a component that can augment the potential for stability and durability when incorporated into asphalt mixtures [15].

Acquiring fillers is costly and depletes resources from natural or manufactured sources, prompting a pressing need to identify more economically and ecologically viable alternatives. This has motivated researchers to investigate the feasibility of leveraging waste as a substitute for conventional counterparts [16].

In many regions of Iraq, the primary constituents of construction and demolition waste are bricks, cement concrete, ceramics, mortar, and soil. According to reports, around 259 brick manufacturing facilities in Iraq produce millions of metric tons of brick yearly [17]. Due to conventional building practices and outdated production techniques, bricks comprise the largest fraction of construction and demolition waste, especially in developing countries [18]. Given that the average lifespan of brick structures in Iraq is approximately 30 years, this has resulted in a substantial accumulation of discarded bricks and will continue to generate more in the future.

Numerous studies have investigated the utilization of BP as an alternative to the conventional filler in HAM [19]. It was observed that asphalt mixtures containing BP require a relatively higher asphalt content than conventional mixtures to meet the design criteria. This is attributed to the high surface area of brick dust particles and their hydrophilic nature, which results in greater asphalt absorption [20-22]. However, incorporating BP as a filler in asphalt mixes has demonstrated improvements in the mechanical properties of the mixes. Experimental work has been conducted regarding replacing mineral filler in asphalt mix with BP as a substitute for conventional filler materials [23-25]. The findings suggest that the Marshall stability was higher for e BP filler compared to other mixes with a relatively higher binder ratio, while it provided mechanical and volumetric specifications similar to those of conventional mixes, largely meeting the specified requirements.

A laboratory investigation revealed that the utilization of recycled brick debris would substantially enhance the moisture resistance of asphalt composites and diminish deformation under high-temperature service conditions, outperforming alternative fillers, such as limestone dust and recycled concrete waste dust [26]. The influence of BP on the performance of pavement surface layers was investigated though the evaluation of samples based on Marshall characteristics, water resistance, and indirect stiffness modulus at various temperatures [27]. The findings revealed that stiffness and frost resistance decrease when 50% of the filler is replaced with BP. However, the study showed that it is feasible to substitute up to 50% of the conventional filler with BP without compromising the essential properties of the asphalt mixture. The potential of four construction waste materials, including waste concrete powder, BP, limestone dust, and waste glass dust, to be used as fillers in bituminous mixes, employing a decision-based ranking methodology, was explored, [28]. The study demonstrated that mixtures incorporating lime dust and brick dust fillers were more cost-effective and environmentally friendly than traditional stone dust mixtures.

The reliability of using waste brick dust as an alternative siliceous aggregate filler in asphalt mixes was researched suggesting that as the amount of brick dust increases, Marshall Stability rises, while flow decreases [29]. Furthermore, BP demonstrated maximum resistance against permanent deformation and higher ITS when fully replacing a natural filler. Additionally, mixes containing brick dust exhibited greater resilience to moisture damage compared to conventional mixes. Similarly, studying the potential of waste BP and iron dust as substitutes for stone dust fillers in bituminous mixtures resulted in observing increased Marshall stability and ITS values in mixes with brick dust [30].

This study evaluates the use of BP as a cement filler replacement in HAM. The performance of mixes with different BP proportions was compared to local specifications to determine the optimal cement filler replacement ratio with waste BP. The mixture characteristics were assessed through the Marshall properties, moisture damage, and ITS tests. The BP-modified mixes were compared to the control mixture and the results were used to assess the feasibility of using BP as an asphalt filler.

II. MATERIALS USED

This study investigates the materials used, formulates mixes with varying proportions of BP filler compared to conventional PC based filler, and evaluates the suitability of BP as a filler in HAM. The necessary materials were sourced locally. They were extensively employed in the construction of roads in Baghdad to emulate the actual performance of asphalt pavements for local roads developed in Iraq, with the potential of providing a laboratory environment for further analysis.

A. Aggregate

The study utilized crushed quartz aggregate sourced from the Al-Nibaee quarry in Baghdad City, which is a commonly employed material for conventional HAM production in central Iraq. The fine aggregate gradation ranged from passing the 4.75 mm sieve to being retained on the 0.075 mm sieve, while the coarse aggregate gradation extended from the maximum nominal size of 12.5 mm to the 4.75 mm sieve size. The physical characteristics of the coarse and fine aggregates are presented in Tables I and II, respectively [21]. The aggregate gradation selection adhered to the SCRB standards, as depicted in Figure 1, by following the mid-point gradation to meet the pavement's wearing layer specifications [31].

TABLE I. PHYSICAL PROPERTIES OF COARSE AGGREGATE

Property	Standard	Results	SCRB Specification
Bulk density (gm/cm^3)	ASTM C127	2.602	-
Apparent density (gm/cm^3)	ASTM C127	2.645	-
Water absorption (%)	ASTM C127	0.51	-
Loss angels abrasion (%)	ASTM C131	20.6	30% Max
Soundness by sodium sulfate solution (%)	ASTM C88	3.4	10% Max
Flatness and elongation (%)	ASTM D4791	2.2	10% Max
Fractured particles (%)	-	97	95% Min

TABLE II. PHYSICAL PROPERTIES OF FINE AGGREGATE

Property	Standard	Results	SCRB Specification
Bulk density (gm/cm^3)	ASTM C128	2.642	-
Apparent density (gm/cm^3)	ASTM C128	2.691	-
Water absorption (%)	ASTM C128	0.675	-
Sand equivalent (%)	ASTM D2419	56	45% Min

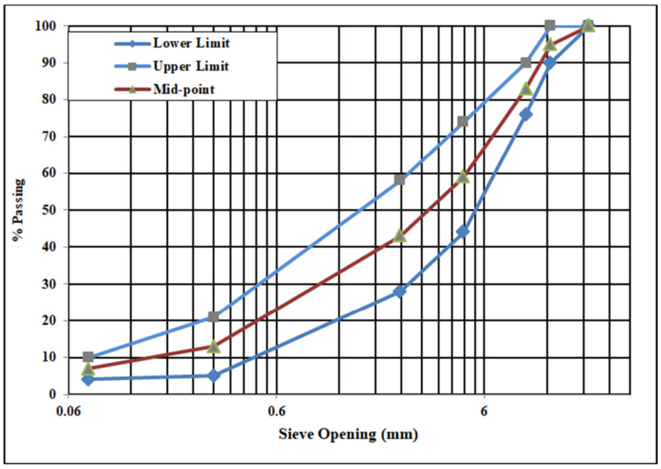

Fig. 1. Aggregate gradation for wearing course SCRB (R/9).

B. Mineral Fillers

Two types of mineral filler that pass through a 0.075 mm screen have been investigated. The first is Mass Company's Ordinary PC Type I. The second is BP filler, which was produced by crushing residual waste clay bricks from a demolished building in Baghdad, Iraq, using the crushing machine shown in Figure 2.

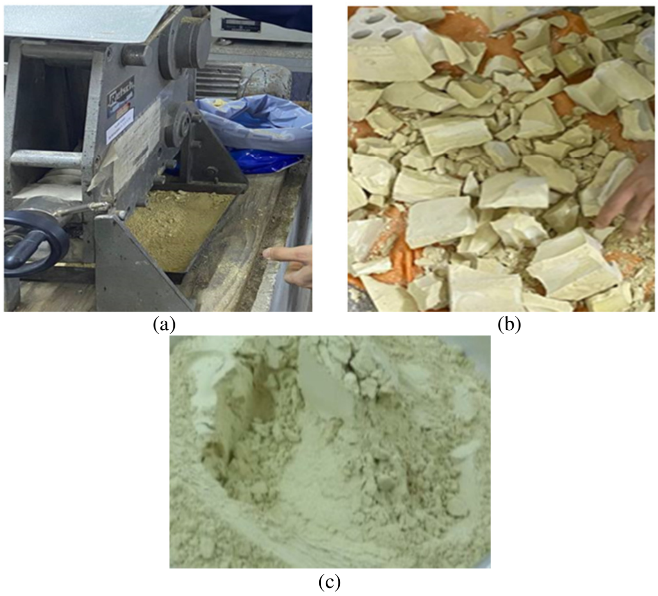

Fig. 2. Preparation of the BP filler. (a) crushing mchine, (b) residual waste clay bricks, and (c) BP filler.

The resulting BP powder was dried at 80 °C for 10 hours and then sieved to a particle size of 0.075 mm or less. The chemical composition and physical properties of the PC and BP are portrayed in Tables III and IV, respectively

TABLE III. CHEMICAL COMPOSITION OF CEMENT AND BP MINERAL FILLERS

Chemical Constituents	Result (%)	
	OPC	*BP*
Loss on Ignition (L.O.I)	2.24	1.22
Silica (SiO_2)	21.77	58.91
Lime (CaO)	61.90	20.2
Magnesia (MgO)	3.91	3.05
Sulfuric Anhydride (SO_3)	2.50	0.81
Ferric Oxide (Fe_2O_3)	3.33	2.35
Alumina (Al_2O_3)	4.76	11.73
K_2O	0.43	0.86
Na_2O	0.11	0.88

TABLE IV. PHYSICAL PROPERTIES OF PC AND BP MINERAL FILLER

Property	Result (%)	
	OPC	*BP*
Specific gravity	3.11	2.81
Passing sieve (0.075mm)	94%	99%
Surface area (m^2/kg)	390	467
Pozzolan activity Index at 7 days (%)	-	89.7
Water absorption (%)	-	1.0

C. Asphalt Binder

Penetration grade 40/50, obtained from the Al-Dourah refinery in Baghdad City, was the bitumen binder employed in this research. The physical properties of the applied asphalt binder are listed in Table V [31].

TABLE V. PHYSICAL ATTRIBUTES OF THE USED ASPHALT BINDER

Property	Designation	Testing Result	SCRB Specification
Penetration 100gm, 25°C, 5 sec. (0.1mm)	ASTM D5	45	40-50
Kinematic Viscosity at 135°C (Cst.)	ASTM D2170	395	-
Softening Point (R&B), (°C)	ASTM D36	52	-
Ductility (25°C, 5cm/min.), (cm)	ASTM D113	135	>100
Specific Gravity	ASTM D70	1.04	-
Flash Point, (°C)	ASTM D92	295	>232
Residue from thin-film oven test (ASTM D1754)			
Retained penetration, (%)	ASTM D5	58	>55
Ductility (25°C, 5 cm/min), (cm)	ASTM D113	52	>25

III. EXPERIMENTAL WORK

The effects of substituting varying percentages of PC filler with BP on the Marshall properties, ITS, and moisture resistance of a typical wearing course asphalt mix have been studied in this study using the same aggregate source and gradation, as well as asphalt binder. The traditional cement filler was substituted by brick dust in four weight-based increments of 25%, 50%, 75%, and 100%. The Marshall Mixture design method was used to determine the ideal asphalt content which in turn was utilized to prepare the asphalt mixtures for further testing.

A. Mix Design Method

The asphalt mixes are produced deploying the Marshall mixture design method in line with the Iraqi specification [31]. Quantities of BP were utilized as mineral filler instead of cement filler. Marshall cylindrical samples with a diameter of 50.8 mm and a height of 63.5 mm were prepared in accordance with ASTM D 1559 [32]. To fabricate the Marshall specimens, the aggregate is blended with the asphalt binder at temperatures between 150 °C and 170 °C, and the specimens are compacted with 75 blows per end using a Marshall hammer. The samples are then maintained at room temperature for 24 hours prior to being extracted from the mold for testing.

The Marshall stability and flow characteristics of each specimen were evaluated. The specimen underwent a 30-minute water submersion at 60 °C, followed by compression at a constant rate of 50.8 mm/min on the horizontal plane to determine the maximum load resistance and associated flow value. The volumetric properties of the asphalt mixes were then calculated. The optimal binder content is defined as the average of three values: maximum stability, maximum bulk density, and 4% air voids, in accordance with the Iraqi standards, as evidenced in Table VI [31].

TABLE VI. OPTIMUM BINDER CONTENT FOR THE PREPARED MIXTURES

BP Replacement Rate (%)	0	20	50	75	100
Optimum binder content (%)	4.60	4.95	5.20	5.30	5.60

B. ITS Test

The ITS test was employed to assess the tensile characteristics of asphalt mixtures. For each mixture, a set of cylindrical samples was fabricated using the Marshall methodology as outlined by ASTM D-1559 [32]. The experiment was conducted at multiple temperatures to investigate the influence of temperature on the properties of the asphalt mix. Each set of samples consisted of nine cylindrical specimens, with three of them having been tested at each temperature. During the test, the center of the sample's vertical circular plane was subjected to a vertical compressive load at a rate of 50.8 mm/min. The maximum load resistance observed was recorded as the ITS, which was then calculated according to (1):

$$ITS = \frac{2 \cdot P}{\pi \cdot D \cdot T} \quad (1)$$

where T is the test sample's height, D is its diameter, P is its maximum test force.

C. Moisture Damage Test

Asphalt-concrete mixes face a significant threat from water exposure. Moisture can lead to the premature deterioration of flexible pavements [33]. The durability and performance of HAM are adversely affected by moisture damage resulting from water sensitivity. To assess HAM's susceptibility to water, the moisture damage test evaluates and compares the strength or stiffness characteristics before and after water conditioning following the respective test protocol [34].

The Marshall technique was used to produce a set of six samples. The specimens were designed to have air voids of 7±1% after compaction. Three unconditioned specimens were tested at 25 °C as the control group. Another three samples were subjected to an 80% saturation conditioning phase, followed by a freezing cycle at -15 °C for 16 hours, and then submerged in warm water at 60 °C for 24 hours. All samples were then tested using an ITS test, which measured the force required to break the sample while it was loaded at 25 °C under constant vertical pressure at a rate of 50.8 mm/min. The ITS of the conditioned and unconditioned samples was analyzed to determine the TSR according to (2).

$$\text{TSR} = \frac{\text{ITS}_c}{\text{ITS}_d} \quad (2)$$

where ITS_c is the conditioned specimens' ITS, and ITS_d is the unconditioned specimens' ITS.

IV. RESULTS AND DISCUSSION

A. Marshall Properties

As a consequence of the Marshall test, many Marshall attributes at various BP contents were identified for each mix, including Marshall stability, flow, unit weight, air voids percent (VMT), and Voids in Mineral Aggregate (VMA).

As the percentage of BP increases, the optimal asphalt content also rises, as depicted in Figure 3. The mixture comprising 100% BP exhibits the maximum optimal asphalt content at 5.4%. In contrast, the control mixture with 0% BP had the lowest value of 4.8%, where the mineral filler is made entirely of cement. This is attributable to BP's superior absorption capacity, which can be attributed to its larger surface area compared to that of cement, as evidenced by the filler's physical properties. The findings presented here are consistent with the outcomes of previous research [20]. Figure 4 shows the Marshall Stability results. As the BP content in the asphalt mix increases, the Marshall stability also increases.

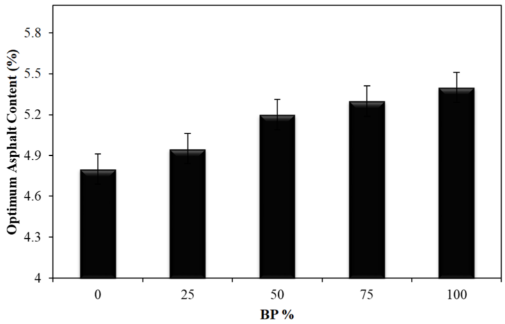

Fig. 3. Optimum asphalt content at different BP content.

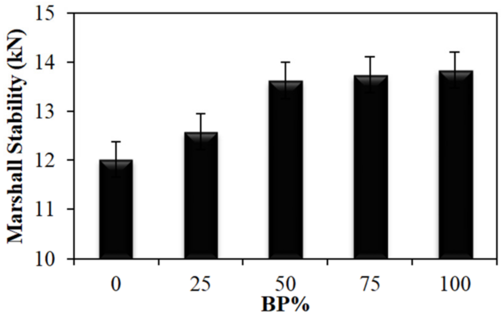

Fig. 4. Marshall stability at various BP proportions.

Adding BP filler to the mixture may create a more viscous asphalt cement binder, leading to higher stability. The maximum stability increase was 13.85% when the BP content reached 100%. These results suggest that the rougher surface and enhanced adsorption of bitumen to the brick particles result in a thicker paste, which contributes to the increased Marshall stability of mixtures containing BP, aligning with previous research in this area [29]. Figure 5 displays the variation in Marshall flow as the amount of BP substituting cement filler is altered. As the proportion of BP in the mixture increases, the flow decreases, implying that mix resistance to permanent deformation also rises. Notably, the flow values for all the mixes exceed the 2 mm of the minimum requirement stipulated by the standard.

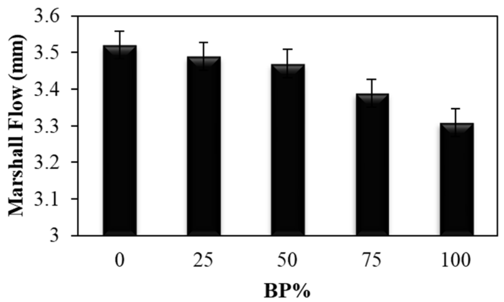

Fig. 5. Marshall flow at various BP contents.

Marshall stiffness represents the ratio of Marshall stability to the corresponding flow value at the optimal asphalt content. It signifies the asphalt mixture's resistance to plastic deformation under loading [35]. Higher Marshall stiffness ratings indicate that the asphalt-concrete mixes utilized in pavement construction will exhibit greater long-term resistance to deformation. The incorporation of brick dust filler resulted in higher Marshall stiffness values compared to the control group mixture, with a progressive increase as the BP content increased relative to cement. The Marshall stiffness values at various BP contents at the ideal bitumen content are illustrated in Figure 5. Based on the findings, a mix containing 100% BP is optimal in terms of rigidity and resistance to permanent deformation, remaining consistent with previous research in this domain [23].

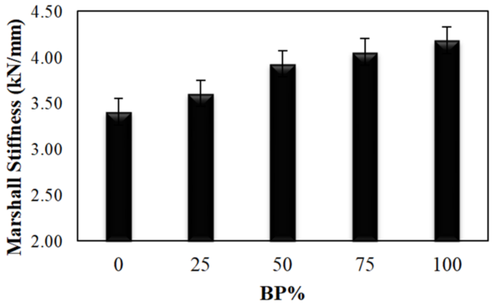

Fig. 6. Marshall stiffness at various BP contents.

Figure 7 showcases the changes in Marshall density at various BP content replacement levels. The findings demonstrate that the Marshall density increases with a rising BP proportion, reaching its peak at 50% BP with an 1.03% increment. However, the bulk density begins to decline with further additions. Although the Marshall densities of all the mixes with varying BP percentages are somewhat higher than the control mix, they are not significantly different from it. These results align with previous research [27]. The relative increase in the asphalt mixture density may be attributed to the finer particle characteristics of BP, which contribute to a denser HMA.

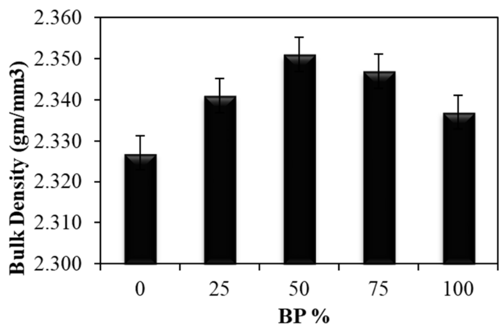

Fig. 7. Marshall density at various BP contents.

Figure 8 illustrates that the amount of brick dust in the combination has no discernible effect on the air-void content of the mixes. All of the mixes' air void contents fall within the 3-5% limit allowed by the Iraqi standard for pavement-wearing courses [31].

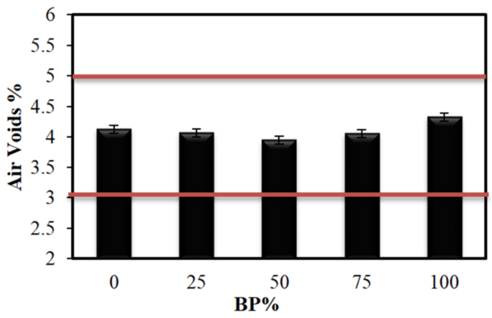

Fig. 8. Air voids percentage at various BP contents.

Regarding the impact of filler made of BP on the percentage of voids in mineral aggregate, the mixture containing 50% BP has the lowest VMA, albeit with a negligible difference. However, it remains higher than the minimum value allowed by the specification, which is 14% and represented by a solid line in Figure 8.

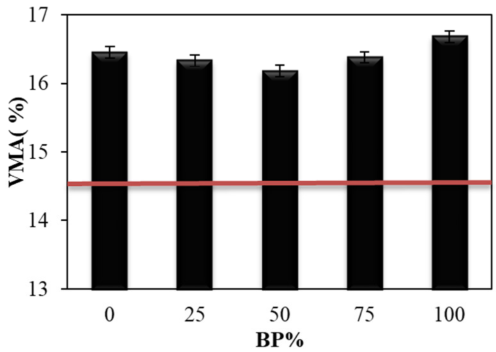

Fig. 9. Voids in mineral aggregates at various BP contents

B. ITS

This study investigates the impact of temperature variations on the ITS of bituminous mixtures when BP is employed as a filler. Typically, an ITS test is performed at 25 °C to assess the tensile strength of bituminous concrete. However, given the fluctuations in pavement temperatures, it is crucial to evaluate the strength characteristics of bituminous mixes at different temperatures. The appropriate use of filler materials can potentially enhance the strength of the mixture. This research aims to examine how the ITS of bituminous mixtures is affected by temperatures of 25 °C, 40 °C, and 60 °C when BP is utilized as the filler. The results presented in Figure 10 display the ITS of asphalt mixtures containing varying amounts of BP at 25 °C, 40 °C, and 60 °C.

The findings indicate that the ITS consistently increased with higher BP content at each reference temperature, but decreased as the temperature rose. Compared to the control mix, asphalt mixtures with BP filler exhibited greater ITS. Completely substituting BP for conventional cement filler yielded the optimal tensile strength. This can be attributed to the rough surface of BP particles, which causes the asphalt binder to absorb more of the material, leading to stronger bonding between the binder and aggregate. This, in turn, enhances the stability and load-bearing capacity of the asphalt mixture. The increases in ITS at 25 °C were 5%, 9.4%, 10.3%, and 11.7% for 25%, 50%, 75%, and 100% BP content, respectively. At 40 °C, the increase rates were 16.4%, 31.5%, 37.9%, and 41.7%, while at 60 °C, the rates were 45.9%, 45.9%, 63.5%, and 69%. These findings suggest that the impact of crushed bricks on the strength of the bituminous mix is more pronounced at higher service temperatures, indicating its suitability for use in hot climates, such as that of Iraq, where rutting is a primary pavement issue.

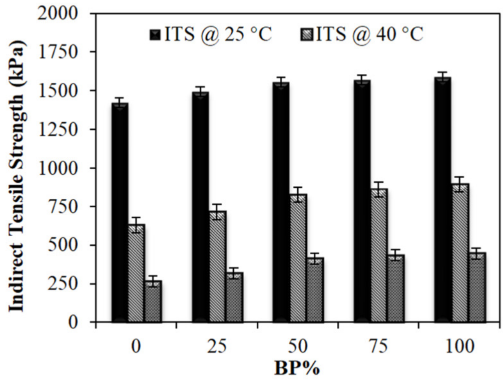

Fig. 10. ITS at various BP contents and temperatures.

C. Moisture Susceptibility Test

The ITS of the mixes has been tested at two distinct conditions, conditioned and unconditioned samples, to examine the moisture damage potential of the mixtures containing varying percentages of brick dust. Figure 11 shows how the ITS changes as the BP content varies for both cases. With an increase in brick dust content, the ITS value rises almost linearly. The dry-conditioned mixes' ITS is lower than that of Figure 10, at a similar temperature of 25 °C, when tested for moisture damage. This is explained by the mixtures' larger air void content.

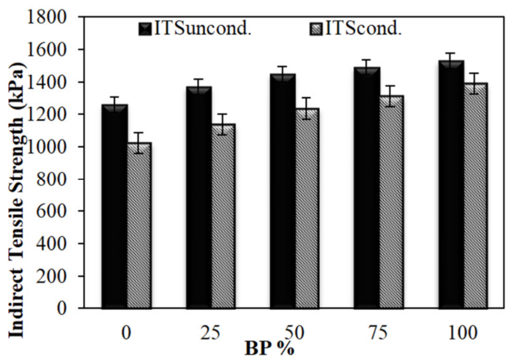

Fig. 11. ITS for conditioned and unconditioned samples.

Furthermore, it was noted that the ITS increase rate is greater than that of unconditioned samples in the case of conditioned samples. For instance, the improvement rate in ITS for unconditioned samples was 21.3%, while it was 35.9% for conditioned samples at 100% of BP content. This shows that the positive effect of BP is greater in the presence of moisture, which gives greater resistance to damage due to moisture.

Figure 12 illustrates the TSR fluctuation with the BP proportion in the mixture. The combinations containing BP have a higher TSR than the reference mixture, indicating they are less susceptible to water damage. According to the American Association of State Highway and Transportation Officials (AASHTO) and the American Society for Testing and Materials (ASTM) regulations, mixes must have a minimum TSR value of 80%. Although all mixes conformed to the specification conditions, mixtures containing a complete cement replacement with BP gave the highest improvement percentage, 12.4%. This proves the enhancement of the moisture resistance property of asphalt mixtures containing brick dust.

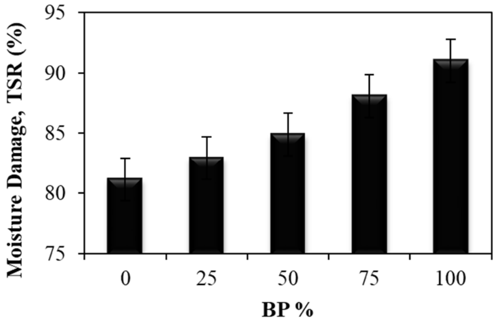

Fig. 12. TSR values at various BP contents.

V. CONCLUSIONS

This research aims to apply one of the sustainability criteria in the road construction domain by utilizing residual Brick Powder (BP) as an alternative to the conventional filler, Portland Cement (PC), to investigate the impact of incorporating this material on the mechanical characteristics of Hot Asphalt Mix (HAM). Based on the findings and examination of the laboratory tests presented in this research, the following conclusions can be drawn:

1. The optimum amount of asphalt increases as the proportion of BP rises. The mix that contains 100% of BP has the highest optimum asphalt content reaching the values of 5.4%, compared to the control mix that contains 0% of BP with a value of 4.8%.
2. As the percentage of cement filler replaced with BP rises, so do the Marshal stability and Marshal stiffness of the asphalt mixes. The growth rate varies depending on the amount of BP content.
3. The Marshall flow value decreases as the percentage of BP content increases.
4. There is no discernible difference in the bulk density, aggregate void content, and mixes' air void content when BP is substituted by traditional cement filler.
5. Using more BP instead of cement filler at the same reference temperature enhances the Indirect Tensile Strength (ITS) of the mixture. However, as the testing temperature increases, the tensile strength decreases. Nonetheless, at 40 °C and 60 °C testing temperatures, the rate of increase in ITS was more pronounced than at 25 °C, suggesting an improved resistance of the asphalt mixture to high-temperature loads, thereby enhancing its resistance to permanent deformation.
6. Compared to the unconditioned samples, the conditioned sample ITS values improved more significantly. This demonstrates the enhanced resilience of the modified HAM against moisture degradation.
7. With a maximum improvement rate of 12.4% at 100% BP content, the moisture damage resistance of the mixes, including BP, is better than that of the reference mix with cement filler.
8. At 100% cement filler replacement and an optimum asphalt content of 5.6%, BP can alter the Marshall properties, strength, and durability of hot asphalt mixtures.

Based on the aforementioned findings, it is possible to conclude that utilizing waste BP as a mineral filler in asphalt mixtures is feasible. This approach will offer Iraqi asphalt pavement developers a cost-effective, environmentally friendly, and long-lasting solution. Further study on its field performance should be carried out to support findings from this study.

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