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ORIGINAL ARTICLE

The Influence of Waste Rice Straw Ash as Surrogate Filler for Asphalt Concrete Mixtures

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ABSTRACT – Mineral fillers in asphalt concrete have improved the mix design qualities significantly. However, the high cost, scarcity, adverse impact towards environment and the inability of conventiona filller to enhance mixtures performance due to the increase in traffic loading have necessitated an investigation into viable alternatives in manufacturing asphalt concrete. Thus, researchers have been looking into using agricultural waste in asphalt pavements to improve sustainability and pavement performance. Waste rice straw (WRS) is a high-volume agricultural waste often burnt for electricity or discarded. In this study, WRS ash (WRSA) was sourced locally, incinerated, ball-milled, and sieved to pass BS sieve No.200 to generate fine powder WRSA, which can be utilised as the surrogate mineral filler. This study evaluated the effect of utilising WRSA as a partial substitute of mineral filler on the volumetric and Marshall properties of the WRSA modified asphalt mixtures. The tests were conducted on a series of asphalt concrete specimens prepared based on Marshall's design with the optimal bitumen content for all varying substitution percentages 0 (control), 25, 50, 75, and 100% WRSA and, the engineering properties of the asphalt mixtures were investigated. The study outcomes show that using WRSA as a surrogate filler inmproves asphalt concrete's Marshall stability and quotients value by 33% and 61% at the optimal replacement of 75%. Based on the result, it can be clinched that WRSA can be incorporated as a filler surrogate to promote sustainability.

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INTRODUCTION

Because of its flexibility, economy, strength, and ability to provide a safe driving condition for road users, asphaltic concrete (AC) mixtures are the most often utilised asphalt in Malaysia for major roads [1]. Even though the road did not reach its design life, the growth in damage on Malaysian flexible pavement has become a severe problem [2]. As a result, improved road pavement constructions are required to decrease pavement deterioration and defects [1, 2]. Furthermore, the climate in Malaysia is causing the road surface to deteriorate, resulting in large potholes [2, 3]. Because asphalt's qualities are stiff in a cold environment and soft in warm weather, it cannot endure extreme weather fluctuations and the maintainnces of the road is in request regularly [1, 4]. Waste is progressively being utilize as a substitute for pavement materials to conserve natural resources and facilitate conservation. The production of agricultural waste and biomass waste is increasing, and many developed economies have realised the need for waste utilisation in tackling this a problem that is rapidly expanding [5, 6]. Thus, it's becoming more popular to use biomass waste. Waste as auxiliary material in the building sector has several advantages, including lower construction costs, better sustainability, and improved pavement performance [7, 8]. Biomass waste was found to be amongst the most beneficial asphalt mixture modifiers.

Rice one of the most important cereal crops on the planet, and majority of the global total consumes it as a key source of energy and protein [9]. During rice production, rice straw (RS) and rice husk (RH) are the most common agricultural wastes (or biomasses) produced. Rice straw is a by-product of rice harvesting. The Rice straw is generated on average of 67 million tonnes worldwide each year [10]. Rice straw is a desirable fuel for energy production due to its global abundance. It is a crucial food crop that generates massive biomass residues worldwide, as well as a silica-rich C3 crop growing in wetlands [9]. The biomass RS and RH ashes are formed during the combustion process known as rice husk ash (RHA) and rice straw ash (RSA). Some studies evaluate the utilisation of RSA as a supplemental component in cement. Sun, et al. [11] investigated concretes with RSA as a partial Portland cement (PC) substitute. The outcomes show improvement in density, compressive and flexural strengths, and durability. Munshi, et al. [9] investigated the use of RSA as a pozzolanic material in cement mortars and found that replacing 10% PC for RSA increased compressive strength by 12.5%. The addition of RSA has no significant impact on setup times. As a result, scientists discovered RSA possess pozzolanic properties, and they advised that a study be conducted to enhance combustion conditions to get higher-quality ash. Hidalgo, et al. [10] also evaluated the use of RSA in cementitious mixtures; the study's outcome shows that after 3 days, mechanical testing revealed samples had a strength activity index of up to 90 and 80 %, respectively, with 15 and 30 % RSA. These values improve to 107–109 % after 90 days of curing.

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Pandey and Kumar [13] investigated the effects of substituting PC with RSA, micro silica (MS), and a mixture of both components to construct pavement concrete. They suggested a blend of 5% RSA and 7.5 % MS, which resulted in compressive strength of 53.6 MPa after 28 days of curing. Also, an investigation by Jaya, et al. [13] evaluated the influence of black rice husk ash (BRHA) on the characteristics of asphalt mixtures at various ageing conditions. By weight of bitumen, BRHA was incorporated to the asphalt mix in proportions of 0%, 2%, 4%, and 6%, respectively. According to the findings, the outcome shows that's asphaltic concrete with BRHA also performed better than the ordinary specimen. Furthermore, because of the aging reaction that the mixtures face during the aging process, long-period oxidation mixtures performed was improved compared to short-period ageing mixtures. In conclusion, the optimal amount of BRHA in the asphalt mixture was between 4% and 6%. Which shows better in terms of voids, stiffness, and creep modulus. The influence of RHA on the mechanical properties of asphalt concrete was similarly assessed by Helal, et al. [14]. It was observed that the Marshall stiffness is improved, rut depth is reduced, and indirect tensile strength values are reduced are increased when RHA is used. In addition, the optimal substitution ratio is 50 % RHA: 50 % LSD. Also, RHA-containing mixes have better dynamic modulus and flow number values.

Previous studies on utilising RSA as cement replacement have also proven to show improvement in the mechanical properties of concrete. On the other hand, this strategy is consistent with existing and future global policies aimed at decreasing waste, reutilising conventional materials, and processing discarded waste into novel resources for other purposes. However, only a few studies are available on the incorporation of waste RSA (WRSA) in the pavement industry, especially as a filler substitute. WRSA was used as a mineral filler substitute in this study to create a novel asphalt mixture design mix with improved properties. This waste material was selected because it is readily available, generally abundant, and aligns with current and future natural resource depletion and recycling trends. This is the most efficient way to transform garbage into reusable items. The characteristics of a conventional asphalt mixtures sample compared to a WRSA modified asphalt mixtures samples were assessed in a laboratory based on volumetric and Marshall properties.

MATERIALS AND METHODOLOGY

Bitumen

The grade of bitumen employed in this study to produce the asphalt concrete mixtures is bitumen grade 60/70. The bitumen came from the Petronas Refinery Malacca and was chosen for sample preparation because of the tropical environment. Bitumen grade 60/70 describes a variety of bitumen grades that fall between 60 and 70 in terms of penetration value under conventional test conditions. The thermoplastic feature of bitumen grade 60/70 led the substance to soften in high temperatures and stiffen in low temperatures. The bitumen conventional properties are listed in Table 1 based on preliminary laboratory standard tests.

Aggregate

Crushed granite aggregate with a nominal maximum aggregate size (NMAS) of 14 mm was used to make the AC14 asphalt mixes. The mineral aggregates were separated into consignments based on the respective sieve size fraction that passed. The gradation range for AC14 is shown in Figure 1 and Table 1 consist of the aggregate properties. For the study, the aggregate gradation and properties utilised in this study conformed to the Malaysian Public Work Department for Road Works Specification (JKR/SPJ/2008-S4) [15].

Materials Properties

The WRSA was obtained from a rice processing plant and cleaned with water to eliminate adherent dirt or dust. It was then sun-dried for at least 16 hours before being incinerated. After 24 hours, the WRSA was collected and heated in a furnace for 3 hours at 600°C to remove all volatile materials and uncured carbons from the ash and produce a consistent weight. The WRSA was processed for 90 minutes at 120 rpm in a ball mill to remove any larger particles and then sieved to particles smaller than 75 µm. Figure 2 depicts the prepared WRSA used in this investigation. By utilising the X-ray fluorescence (XRF) analysis, the chemical composition and percentages of each oxide present in the study WRSA were evaluated to know the composition and was presented. The specific gravities of ordinary Portland cement (OPC) and WRSA were evaluated using ASTM D854-14 standards. The WRSA's filler effect is determined by its physical features. Table 2 shows the WRSA and OPC's conventional physical parameters. Because properly ground WRSA passes more than 95 % through a 75 µm sieve, the fineness of WRSA is the primary factor of the filler effect. Though, the specific gravity of WRSA is lower than OPC, as indicated in Table 2. Another criterion for effectiveness when utilising WRSA is its large specific surface area. Thus, WRSA is ideal for usage as a substitute cementitious material because of its reactive silica compound, high surface area, and fineness.

Table 1. Properties of materials.

Properties	Specification	Units	Results
Bitumen			
Specific gravity	ASTMD70-18	-	1.024
Penetration	ASTMD5-13	dmm	67
Softening point	ASTMD36-12	°C	49
Ductility at 25 °C	ASTM D113-07	cm	132
Mass loss	ASTM D2872	%	0.02
Combine aggregate			
Aggregate crushing value	BS 812- 110	%	13.67
Aggregate impact value	BS812-112	%	21.83
Bulk specific gravity	ASTM C 127	g/cm^3	2.564
Absorption	ASTM C 127	%	0.52
Fine aggregate			
Bulk specific gravity	ASTM C 128	g/cm^3	2.513
Loss due to abrasion	ASTM C 131	%	23.2
Absorption	ASTM C 127	%	1.04
Flat and elongated tests	ASTM D 4791	%	17.4

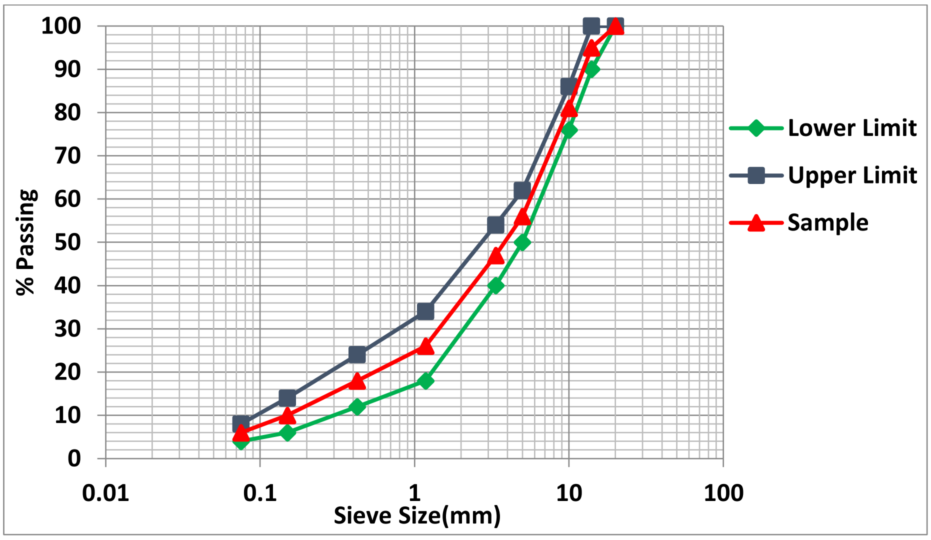

Figure 1. Aggregate gradation limits for AC14 dense-graded wearing course.

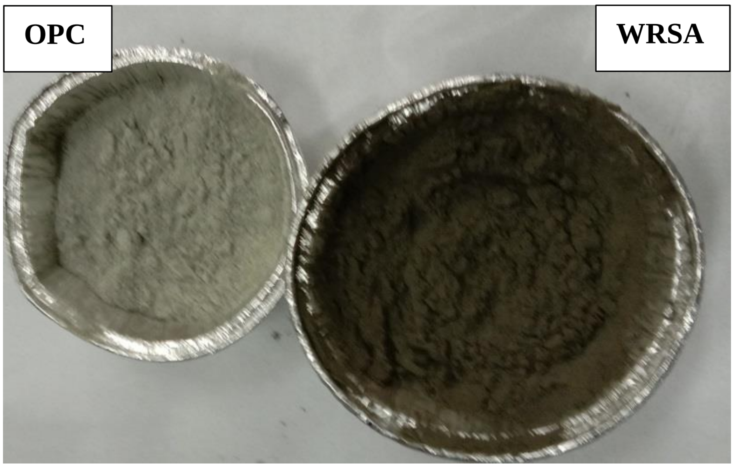

Figure 2. OPC and WRSA for the study.

Table 2. Study filler materials chemical composition and physical properties.

Filler material		OPC	WRSA
Oxides	SiO_2	22.1	74.89
	Fe_2O_3	3.8	1.33
	Al_2O_3	5.9	1.06
	K_2O	0.3	6.09
	SO_3	2.5	1.21
	CaO	66.1	2.89
	M_gO	1.5	1.96
Specific gravity		3.13	2.31
Surface area(m^2/kg)		348	389
% Passing 75µm		91.4	96.3
Colour		Grey	Dark grey

Methodology

Sample preparation

The Marshall mix design was employed, with the primary goal of the design being to achieve the mixture's optimum bitumen content (OBC). The combination (aggregate, mineral filler and bitumen) was blended and compacted at 170 ±5°C and 160 ±5°C, respectively, using 75 blows to the upper and opposite sides of the sample.

Volumetric properties

The samples' bulk density was calculated according to ASTM D2726, respectively. We record the weight of a dry specimen in the air first, then totally submerge the specimens in water for 3 to 5 minutes before taking the weight in the air. The specimen's weight in air was calculated after drying the surface and we evalaute the maximum theoretical specific gravity. Furthermore, the void in total mix (VTM) for the samples was calculated using theoretical maximum density (TMD). The volumetric properties like bulk unit weight (BUW), voids in the total mix (VTM), voids filled with bitumen (VFA), and voids in mineral aggregates were all measured in this study using the Equations 1-6.

$$SG\ \ aggreagte = \frac{100}{\frac{\%\,Coarse}{SG_{Coarse}} + \frac{\%\,Fine}{SG_{Fine}} + \frac{\%\,Filler}{SG_{Filler}}} \tag{1}$$

$$SG\ \ \text{theory (max)} = \frac{100}{\frac{\%\,Bitumen}{SG_{Bitumen}} + \frac{100-\%\,Bitumen}{SG_{Aggregate}}} \tag{2}$$

$$BUW = \frac{W_{Air}}{W_{Air} - \ W_{Water}} \tag{3}$$

$$VTM\ (\%) = 100 \times \left(\frac{SG_{Max} - SG_{Bulk}}{SG_{Max}}\right) \tag{4}$$

$$VMA\ (\%) = \ 100 - \left(\frac{(SG_{Bulk})\ (100 - \%Bitumen)}{SG_{Aggregate}}\right) \tag{5}$$

$$VFB\ (\%) = \ 100 \times \left(\frac{VMA - VTM}{VMA}\right) \tag{6}$$

Where SG means the specific gravity and W means weight

While, the Marshall properties were computed using the ELE Multiplex 5.0-E Marshall testing equipment, the samples were then tested for Marshall properties. Marshall stability and flow tests were performed on cylindrical compact specimens with a width of 101.6mm and a height of roughly 63.5mm as shown in Figure 3a. For 40 minutes, the samples were submerged in a 60°C water bath. before being loaded to failure with arched steel loading panels at a constant compression speed of 50.8mm/min on compact samples with various bitumen contents of 4-6 % until it failed and the the Marshall stability, flow were observed abd recorded from the Marshall machine.The Marshall quotient of each mix was evaluate by taking the ratio of the stability to flow falue as shown in Equation 7. For the mixtures,the OBC was acquired according to the JKR threshold for AC14 and tested for mixture design parameters specified by Malaysian Public Work Department for Road Works Specification [15], which confirmed that it was 5.13 % by weight of the mixtures. Mixtures containing WRSA as a surrogate for OPC in various ratios (0, 25, 50, 75, and 100 %) were prepared for analysis. The

OBC attained for the control sample was used to construct the WRAS modified asphalt mixtures to compare the volumetric and Marshall properties of the modified mixes to the control mix without taking bitumen content as a distinct factor. Figure 3b depicts the Marshall testing equipment.

$$Mashall\ quotient\ (kN/mm) = \frac{Marshall\ stability}{Marshall\ flow} \tag{7}$$

Figure 3. (a) Marshall samples and, (b) Marshall testing machine.

RESULTS AND DISCUSSIONS

The impact and influence of utilizing WRSA as a surrogate filler on the volumetric and Marshall characteristics of asphalt concrete mixtures is discussed.

Bulk unit weight (BUW)

The mixture bulk unit weight (BUW) and voids in total mix (VTM) values for the various blends are depicted in Figure 3 and discussed below. It was noticed that when the substitution content of WRSA in the mixes increases, the bulk density declines slightly compared to the control mixture. This can be attributed to WRSA having lower specific gravity than OPC, which decreases mix density when more of it is added. These findings are consistent with previous studies when periwinkle shell ash [16] and rice husk ash [17] were used as filler replacements in asphaltic mixes, a decline in BUW was observed. Also, in comparison to the control mixes, the WRSA mixtures had a lower density and more air spaces.

Voids in total mix (VTM)

The rise in WRSA content as filler surrogate causes a linear trend in the VTM, resulting in larger air voids in the mix as observed in Figure 4. Because the WRSA filler has a greater specific surface area, it entails more bitumen to cover the surface of the WRSA particles. In the same way, the influences of WRSA in the bitumen matrix congeals the bitumen-filler mastic, which hampers densification during compaction and leads to larger voids [18]. From the study, as WRSA was added, the density of the mixtures dropped as air spaces increased. A similar tendency was observed when RHA was utilised as a filler substitute [17]. The outcome values for all the mixtures are within the Malaysian Public Work Department for Road Works Specification guidelines for asphalt mixtures wearing of 3 to 5% air void.

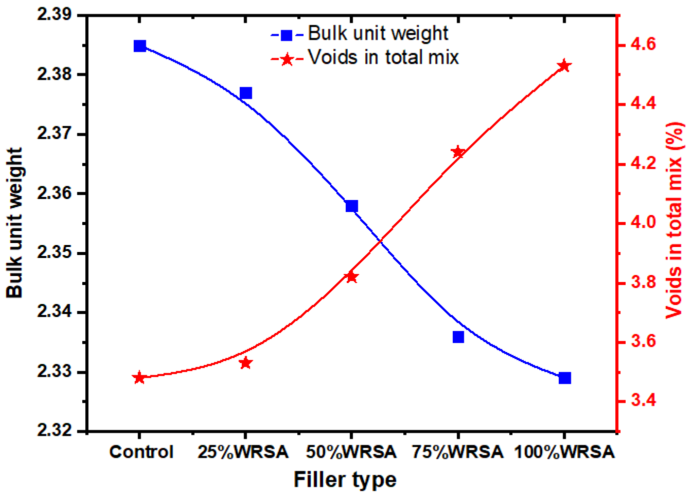

Figure 4. Influence of WRSA content on the BUW and VTM of asphalt mixtures.

Voids in mineral aggregate

The relationship between the WRSA content and mixtures voids in mineral aggregate (VMA) is shown in Figure 5. The VMA is vital when producing asphalt mixtures because it guarantees that the bitumen film coating is adequate to protect the pavement from moisture and abrasive stresses from the tires [19]. The VMA is inversely proportional to the mixture's bulk density. The VMA increases as the WRSA filler content increases in all mix types. Compared to OPC, asphalt mixtures containing more WRSA exhibited higher VMA, likely due to WRSA's more significant porosity, as seen by surface area and percentage passing values. All of the VMA values for mixtures are within the Malaysian Public Work Department for Road Works Specification [15].

Voids filled with bitumen

The effect of WRSA content on the mixtures void filled by bitumen (VFB) is decpicted in Figure 5. The term void VFB refers to the ratio of VMAs inhabited by bitumen. The VFB measures the quantity of effective bitumen in a mixture and is inversely proportional to the number of air pockets. Therefore the VFB drops as the number of air voids rises [20]. This similar trend was also observed as observed in Figure 5. In general, the introduction of WRSA decreased VFB in the mixes because it has a greater specific surface area, which requires more bitumen to cover the surface, resulting in less VFB [18] compared to OPC. This can also be attributed to the WRSA filler's improved bitumen absorption since the presence of ferrous oxide (Fe_2O_3) helps absorb surplus oil from the asphaltic mixture [21]. The VFB values for all the WRSA-infused mixes are lower than the reference mix, signifying that the incorporation of WRSA lowers the VFB values. WRSA mixes have lower VFB levels than traditional mixes. As a result, in tropical areas, like Malaysia, these materials may be favoured as filler.

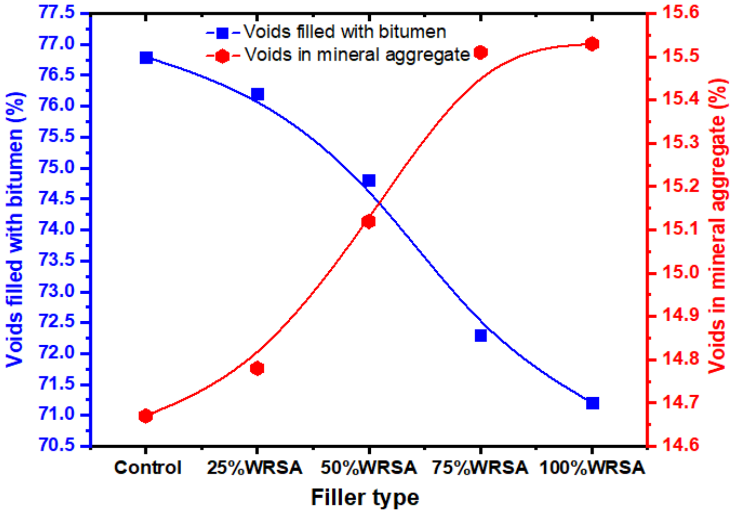

Figure 5. Influence of WRSA content on the VFB and VMA of asphalt mixtures.

Marshall stability

Figure 6 depicts the Marshal stability and flow differences of several asphalt mixtures. The stability values climb to a maximum value before decreasing as the WRSA content replacement increases. This shows that the amount of WRSA used as a filler material should be optimised to enhance mixture stability. When periwinkle shell ash [16] and oil palm ash [22, 23] were used as filler replacements in asphaltic mixes, a similar tendency was found. The WRSA particles acting as a reinforcing ingredient to enhance the stiffness and cohesion of the mastic might explain the improvement in Marshall mixes of WRSA modified asphalt mixtures. Also, when rice husk ash was employed as a filler, a similar trend was observed [17]. Furthermore, the increased porosity of WRSA mixes may be linked to their strong propensity to absorb more bitumen, resulting in improved performance. This improves the adhesive force between the bitumen and the aggregates, improving stiffness and durability [24]. This increase in Marshall characteristics for WRSA asphalt mixtures may be ascribed to the fact that WRSA filler particles tends to interact with the bitumen mastic and thus function as a reinforcing ingredient for the asphalt mixtures, thus increasing cohesiveness and stiffness.

Marshall flow

The Marshall flow refers to the ability of asphalt mixtures to deform without cracks as a result of successive settlementment and is proportional to the internal friction. Mixes with greater flow values are more inclined to deform under stress, whereas blends with very small flow values are stiff and so crack more easily. The relationship of utilizing WRSA on mixtures Marshall flow According to the study's findings, increasing WRSA concentration leads to a downward trend in the flow values, as shown in Figure 6. This might be because of WRSA's lower specific gravity and larger specific surface area. Also the decline in flow value as theWRSA content increass could be due to interaction between the WRSA and the bitumen in mixtures. The flow values for all mixtures fell within predetermined JKR standard ranges of 2-4 mm, indicating that adding wastes didn't make the mix too flexible or rigid.

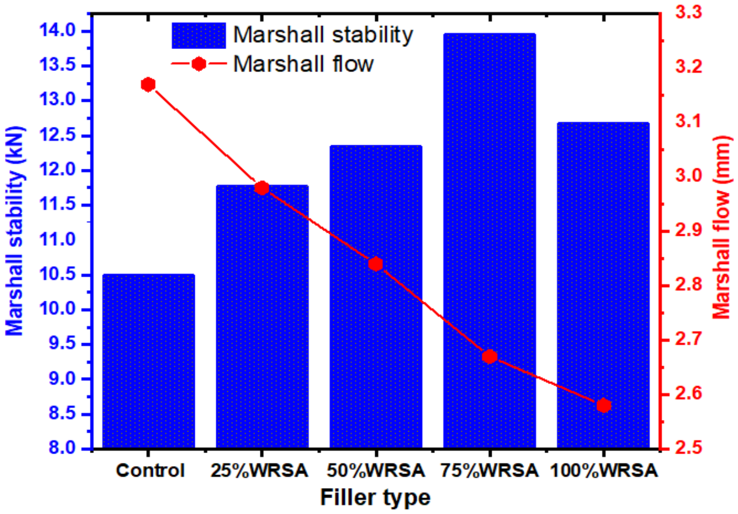

Figure 6. Influence of WRSA content on the Marshall stability and flow of asphalt mixtures.

Volumetric properties

The ratio of stability to flow may be used to determine the Marshall quotient (MQ), which helps to give hints of mixtures stiffness. The effect of WRSA content on mixtures MQ is shown in Figure 7.The MQ is widely acknowledged as a measure of a material's resistance to shear loads and rutting [25]. Generally, Asphalt mixtures with greater MQ have better stiffness, superior capacity to disperse the imposed load, and stronger creep resistance. It was observed that mixtures incorporated with WRSA as filler have greater MQ values. These can be attributed to its fine and chemical composition. The asphalt mixtures containing various content of WRSA had greater stability than the control mix. This finding suggested that WRSA might help increase adhesion between the bitumen-filler interface and thus can help to improve the mixture stiffness and it was observed that 75% replacemnt is the optimun dosage for enhanced improvement in the mixtures stiffness compared to other mixtures.

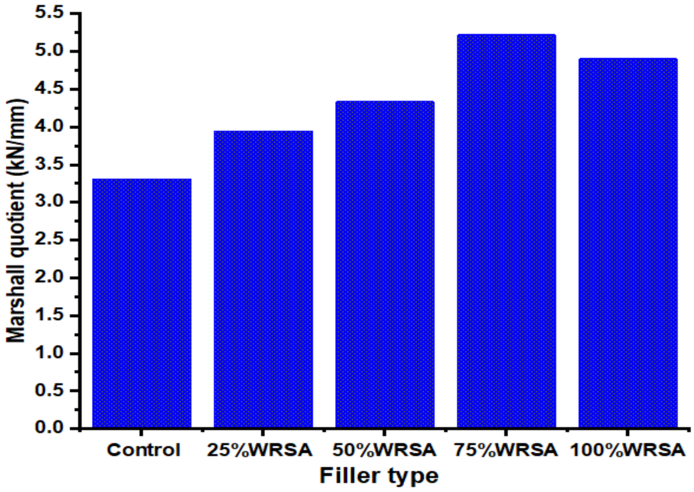

Figure 7. Marshall quotient of asphalt mixtures at varying content of WRSA.

CONCLUSION

This study assessed the viability of utilising WRSA as surrogate filler in asphalt mixtures via volumetric and Marshall properties. Based on the volumetric and Marshall properties, it was observed that for optimum performance of the modified asphalt mixture, the optimum content of WRSA to be incorprated as surrogate is 75%. Because, asphalt mixtures with 75% WRSA shows improve Marshall stability and stiffness compared to the control mixtures with its volumetric properties within the stipulated standard range. In conclusion, incorporating WRSA as a surrogate filler not only help harness sustainability but also enhances pavement properties and is readily available.

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