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The influence of micronized rubber powder and rice husk ash on mechanical, physical and rheological characteristics of asphalt binders and mixtures at high temperatures

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Abstract
This research target to examine the effectiveness of adding rice husk ash and micronized rubber modifier powder (MRP) on mechanical and physical properties as well as rheological characteristics of bitumen binders and mixtures within elevated temperatures. Three concentrations 2%, 4%, and 8%, and 6%, 12%, and 18% of RHA and MRP respectively were employed to prepare modified asphalt specimens in addition to the control specimens. To straighten the features of asphalt binders and mixtures, several experiments were conducted like penetration, softening point, elastic recovery, wheel tracking test, and rotational viscosity tests which are assessed with basic tests, while rheological characteristic tests as dynamic shear rheometer test are conducted to measuring material's flow and deformation properties under stress, measured by using DSR devise which is considered as the most advanced rheometer's devise. Obtained results showed that, RHA and MRP had affirmative leverages on properties of asphalt binder and mixtures. Besides, the new hybrid modified asphalt with percentage of 8% RHA and 18% MRP could be deemed as the best favorable dosage for premium overall rendering of amended blends and binders.

Nomenclature and units

Pa.s	Pascal second
µm	Micrometer
s	Seconds
g	Gram
kg	Kilogram
MPa	Mega Pascal
ºC	Degrees Celsius
mm	Millimeter
rad/s	Radian per second
g/cm^3	Gram per cubic centimeter

1.0 Introduction

Rice is cultivated annually in enormous amounts about the world. However, there are only two crops produced more than rice; which are maize and wheat. The top nine rice producers are illustrated in Table 1 ("FAO Rice Market Monitor, Volume XXI - Issue No. 1, 2018," ; Zereyesus et al., 2025). About $146x10^6$ metric tons of rice annually was produced by China which was ranked as top-producing country (Crumpler et al.; "FAO Rice Market Monitor, Volume XXI - Issue No. 1, 2018,"). A byproduct through the rice grinding operation is known as rice husk; (Givi, Rashid, Aziz, & Salleh, 2010; Ralph et al., 2025), burning it produces a new substance known as rice husk ash. Every 1000 kg of paddy rice produces approximately 200 kg of rice husk, as a rice husks make up nearly 20% of paddy rice's weight (Ralph et al., 2025). The rice husk ash amount acquired of combustion of 1000 kg rice husks ranges from 150 to 250 kg. This range depends on several factors, including: Rice variety and origin, and burning conditions can result in a dissimilarity of ash content, typically ranging from 15% to 25% of the husk's weight, and sometimes up to 30% ("Bronzeoak. Rice Husk Ash Market Study, Department of Trade and Industry, U.K., Bronzeoak Ltd., 2003.," ; Pode, 2016). Most rice husk waste either dumped into water, burned, or buried as waste material in China (Abdelmagid & Pei Feng, 2019; Zhang et al., 2015), because it contains little protein and a lot of ash, causing water and air contamination and having a considerable negative influences on regional ecosystems.

Rice husk ash had no known interests or applications for numerous years. In recent years, there has been a powerful direction towards employing rice husk ash as additional building materials due to increasing of the inhabitants influence and rates of construction materials (Abdelmagid & Pei Feng, 2019), thus, numerous studies investigated the likely employment methods of rice husk ash, and they had a considerable attention in that area of research. Some researchers have used rice husk ash as a soil alteration due to the fact that the soil has low stability under heavy loads and is generally fragile (F. H. Ali, Adnan, & Choy, 1992; Basha, Hashim, Mahmud, & Muntohar, 2005; OKAFOR & Ugochukwu N. OKONKWO, 2009; "Performance evaluation of cement-stabilized pond ash-rice husk ashclay mixture as a highway construction material," 2017). In addition, many papers have been written in improving the properties of concrete by adding rice husk ash and these papers show that rice husk ash has good ability to lowering bleeding and segregation (Hwang & Chandra, 1996), promotes the compressive force and workability of concrete (Givi et al., 2010), leads to huge enhancement in the permeability features in concrete mixes (Ganesan, Rajagopal, & Thangavel, 2008), and progresses the durability of self-compacting high-rendering concrete (Le & Ludwig, 2016; Li, Liu, Liu, Wu, & Li, 2025). Furthermore, the amount of cement required to prepare the concrete is reduced to a maximum of 20% of the weight (Givi et al., 2010; Gurjar, Choudhary, Aziz, & Mehdi, 2026). Few tries were done by researchers to use and utilization of the RHA for bituminous mixtures (Isberto, Labra, Landicho, & De Jesus, 2021). Sebnem et al. (Sargin, Saltan, Morova, Serin, & Terzi, 2013) investigated the adding of rice husk ash to hot mix asphalt concrete (HMAC) as a filler, and concluded that adding 50% RHA and 50% limestone as a filler showed good effects on the Marshall stability and Marshall flow. Another study has been done in 2017 (Arabani & Tahami, 2017), to study the effectiveness of rice husk ash addition to hot mix asphalt as an asphalt modifier. They found that adding rice husk ash had improved Marshall stability (MS), stiffness modulus, rutting strength and fatigue performance of hot mix asphalt concrete (HMAC).

Waste tire rubber powder applications in pavement construction is a common practice to enhance the pavement performance (Bakheit & Xiaoming, 2019; MacLeod, Ho, Wirth, & Zanzotto, 2007; T. Wang et al., 2018). During the last recent years, to reduce the quantity and cost of building materials, MRP has been vastly used (Baek, Kim, Doh, & Kim, 2009; "Heitzman MA. States of the practice-design and construction of asphalt paving materials with crumb rubber modifier. Pub No FHWA-SA-92-022, FHWA, US Dept of, Transportation, 1992.," ; T. Wang et al., 2018). Several studies (B. Ali & Sadek, 2013; Cong, Xun, Xing, & Chen, 2013; Fontes, Triches, Pais, & Pereira, 2010; Khalaf, Yousif, Tayh, & Jasim, 2023; Palit, Reddy, & Pandey, 2004; H. N. Wang, You, Mills-Beale, & Hao, 2012) reported about adding rubber to asphalt led to increase the viscosity, $G^*/\sin(\delta)$, G^*, softening point and elastic recovery, in contrast, penetration value and δ are declined, therefore, increased the resistance capability to the rutting distresses.

The current work target to examine the influence of adding RHA and micronized rubber modifier powder on physical, mechanical, and rheological characteristics of the bitumen mixtures and binders at elevated temperature through deferent experimentally tests.

Table 1 Top nine rice producers and their production.

Country name	Production in year 2023 (million tons)	The % of Global Production
China	146	28
India	135	26
Bangladesh	37	7
Indonesia	34	6
Vietnam	27	5
Thailand	21	4
Philippines	12.33	2
Myanmar (Burma)	11.9	1.8
Pakistan.	6.6	1

2. Materials and experimental methods

2.1. Materials

2.1.1. Asphalt binder

In the current paper, the utilized bitumen is the virgin asphalt 60/70 penetration graded asphalt binder (penetration graded bitumen, also known as paving grade bitumen), and micronized rubber modifier powder (MRP), were brought from Jiangsu Tiannuo Advanced Material Technology Co., Ltd. /China. The conventional properties of pure asphalt (A-60/70) grad are presented in the Table 2.

Table 2 Physical features for conventional bitumen binder.

Test	Standard	Result	Specification limits
Penetration depth at 25 ºC,100g, 5 sec, (0.1mm)	ASTM D5	64	60–70
Ductility at 25Cº, 5 cm/min), (cm)	ASTM D113	149	Min 100
Kinematic Viscosity at 135 ºC (Pa.s)	ASTM D2170	0.421	-
Softening point (ºC)	ASTM D36	49	Min 46.0
Flash point (ºC)	ASTM D92	316	-
Fire point (ºC)	ASTM D92	330	-
Specific gravity	ASTM D70	1.054	-
Loss on heat %	ASTM D-6	0.05	-
Dynamic Viscosity at 60 ºC (pa.s/s)	ASTM D2171	411	-

2.1.2. Rice husk ash preparation

The implemented rice husk ash in the study was bought from Harbin factory, China. Temperature of burning was controlled to be nearly from 500 °C to 700 °C for two hours to avoid carbonization (Xu, Lo, & Memon, 2013). Afterward, the obtained rice husk ash grinded by employing gristing ball grinder for period of 25 minutes to shape a fine ash, and then the sieve No. 200 mesh (75 µm) size was used (Abdelmagid & Pei Feng, 2019; Isberto et al., 2021). The duration grinding used is 25 minutes because shorter grinding times like 15-30 minutes can produce a finer RHA with high reactivity, while longer grinding periods can lead to agglomeration and potentially less desirable properties for some applications.

2.1.3. Micronized rubber powder

The MRP applied in this survey was general micronized rubber powder (MRP) exceeded out of a No. 80 mesh (177 µm) and kept on screen No. 90 mesh (145 µm) determined by screening, and the physical properties and chemical compositions clarified by Table 3.

Table 3 Chemical components and physical properties of MRP materials.

	Properties	Result	Technical Index
Physical Properties	Density ratio (g/cm^3)	1.13	-
	Moisture (%)	0.7	< 0.75
	Moisture content (%)	0.61	-
	Metal content (%)	0.002	< 0.01
	Relative density	1.10-1.30	-
	Fiber content (%)	0.37	< 0.50
	Break strength (MPa)	13.2	
Chemical Compositions	**Component**	**Content (%)**	
	Ash content	5	-
	Rubber hydrocarbon content mass	39.8	-
	Acetone extract	11	-
	Natural rubber Content	25.8	-
	Relative density	1.2	-
	Carbon black content mass (%)	33	
	Particle size range (µm)	145–177	-

2.2. Preparation procedures and scheme

2.2.1. Specimen elaboration process

For examining the effectiveness of rice husk ash and MRP on the features of the bitumen binder and rheological characteristics, three concentrations were used such as 2%, 4%, and 8% of RHA and 6%, 12%, and 18% of MRP. Firstly, 500 g of pure asphalt was put in the oven at a 180 °C, then through utilizing mechanical mixer at a rate of 1000 rpm, different mass concentrations of MRP were added slowly to the asphalt for 15 min. afterward, the elevated-velocity mixer at a speed of 3000 rpm and 180 ± 5 °C utilized to stir the specimen for 30 minutes, after 30 minutes immediately the rice husk ash (RHA) was added with the same speed of 3000 rpm at 160 ± 5 °C for else period of 30 minutes. The obtained mixtures were moved back again to the mechanical mixer and whiskered by at depressed velocity (<100 r/min) for 10 minutes to remove air from the mixture.

2.3. Test methods

2.3.1. Penetration

Penetration is used to estimate the rigidity of binder according to (ASTM D5), through determining the vertical deepness at 25 °C utilizing a criterion tonnage needle about 100 g.

2.3.2. Softening point (R & B method)

To determine temperatures at which the bitumen binder arrives the specific viscosity, softening point was tested by placing a metal ball on a binder disc, then step by step raising temperature at an average of 5 ± 0.5 degrees Celsius/min until the sample become sufficiently soft for the balls to drop from the space of 2.5 cm according to the specifications of (ASTM D36).

2.3.3. Elastic recovery test

The elastic recovery for bitumen measures its capability to resumption to its authentic condition after being stretched. The elastic recovery defined as the percentage at which asphalt binder restore its original shape after removing the stress (Yildirim, 2007). Elastic recovery conducted same as in ASTM D6084. Firstly, specimens were conditioned in water bath with 25 °C for 90 ± 5 minutes. After that the specimens were elongated with the velocity of 5 cm/minute until it reached to the protraction of 10 ± 0.25 cm. Afterward, immediately sample was cut from the middle and left to recover at ductilometer for duration of 60 min, then the elastic recovery as a percentage was measured using Eq. (1).

$$Recovery\ \% = \frac{E-X}{E} \times 100 \qquad (1)$$

Where:

E is an initial length of the specimen in cm, *X* is the length of the sample with sectioned ends just touching cm.

2.3.4. Rotational viscosity

To evaluate the viscosity at high temperatures, the RV device was used, and since viscosity expresses the ability to pump the bituminous material and process it in hot mixing facilities, it is considered as one of the basic features of the asphalt binder ("The Asphalt Institute. Performance graded asphalt binder specification and testing, SP-1. Lexington (KY): The Asphalt Institute; 2003.,"). Brookfield rotational viscometer apparatus in Figure 1 utilized to gauge the torque required to rotate a spinning wheel in the fluid at a steady, known velocity. This torque is proportional to the fluid's resistance to flow (viscosity). The key components and test procedures are conducted according to ASTM D2170 specifications. 10.5 g of bitumen binders was used to acquire the viscosity values, in this research the specimens' viscosity amounts were calculated at 135 °C with a spindle No.27.

Figure 1: Explain the Brookfield rotational viscometer device.

2.3.5. Bitumen dynamic shear test

The rheological merits of the binder at medium to high temperatures are determined using DSR check. Bitumen dynamic shear test was utilized for characterizing viscoelastic behavior of asphalt binders. DSR experiments conducted to examining asphalt behaviors at elevated temperature, and the bitumen dynamic shear test was achieved with hesitation of 1.59 Hz at different temperatures ranging of 52-82 °C (incremented by 6 °C) under controlled strain, Figure 2, illustrates the DSR device test. The model used was the parallel plates with 25 mm diameter and the distance between them of 1 mm ("K.D. Stuart, W.S. Mogawer, P. Romero, Evaluation of the Superpave asphalt binder specification for high-temperature pavement performance, Association of Asphalt Paving Technologists Proc, 2000.,"). In order to assess resistant of asphalt binder to rutting, complex modulus and phase angle were measured previous and next aging at different temperatures. The RTFO test achieved at 163 °C for the time 85 minutes and air influx at speed of 4000±200 ml/min in accordance with ASTM D2872-04 criterions.

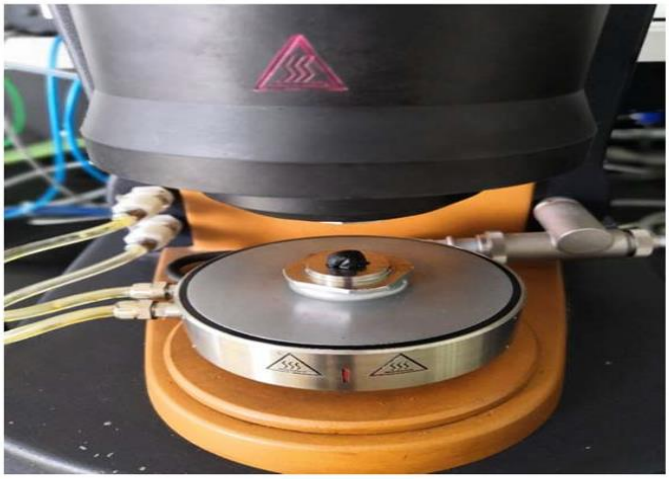
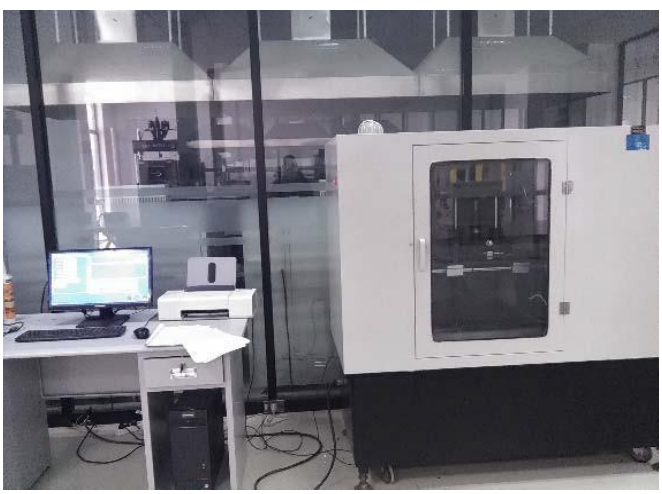


Figure 2: Explain the DSR devise test setup and the specimen.

2.3.6. Wheel tracking test

Wheel tracking test (WTT) conducted to patterns intended by employing the different MRP and RHA concentrations. The specimens produced with the dimensions of 30×30×5 cm using a roller compactor machine. The experiment was done at a 60°C for straighten the rutting resistance. The rolling wheel with 0.7 MPa standard load traversed the sample at fixed velocity of 42 load cycles/ min for 60 minutes. Figure 3 clarifies wheel tracking experiment device setup with specimen. WTT also used for evaluating moisture susceptibility of the hot mix asphalt concerning to the aggregate composition, bitumen stiffness, or adhesion strength amidst aggregate and bituminous asphalt.



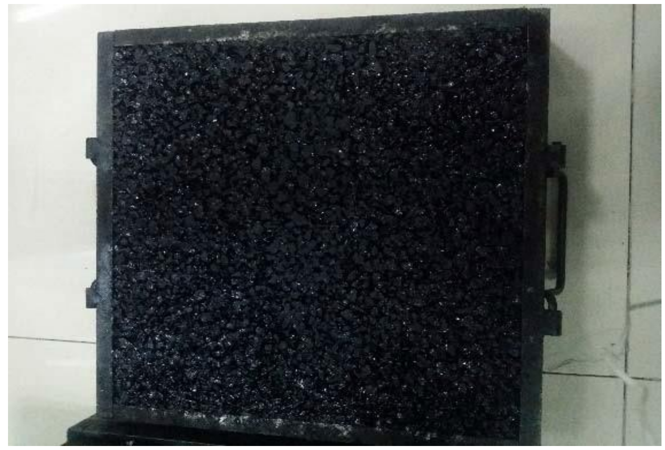


Figure 3: Clarify the view of the WTT test apparatus and sample inside the mold.

3. Results and discussion

3.1. Penetration

Outcomes explained by Figure 4, obvious that whole penetration values were decreased when RHA and MRP content raised. Penetration amount of the pure asphalt was reduced by 45%, 54%, and 60.6% when 4% RHA utilized with 6%, 12%, and 18% MRP respectively which exhibited significant reduction in the penetration values. Due to penetration decreases, the asphalt consistency becomes stiffer, which may enhance its strength against mechanical damage (Zapien-Castillo, Luis Rivera-Armenta, Yolanda Chavez-Cinco, Adriana Salazar-Cruz, & Maria Mendoza-Martinez, 2016). A fall in asphalt penetration value means the bitumen has become harder or more viscous. This characteristic offers certain benefits, primarily related to enhanced stability and resistance to deformation in hot conditions and under heavy traffic.

The key benefits of a lower penetration value in asphalt are: Increased rutting resistance (harder asphalt is less susceptible to softening and flow under high temperatures and heavy and repetitive traffic loads). This significantly reduces the potential for permanent deformation, or rutting, in the wheel paths of the pavement. Also the benefits of a lower penetration value in asphalt improved high-temperature performance, greater load tolerance, and enhanced durability in specific applications. Lower penetration grades are specifically suited for use in warmer or hot climates because they maintain their structural integrity and stiffness when exposed to high ambient temperatures.

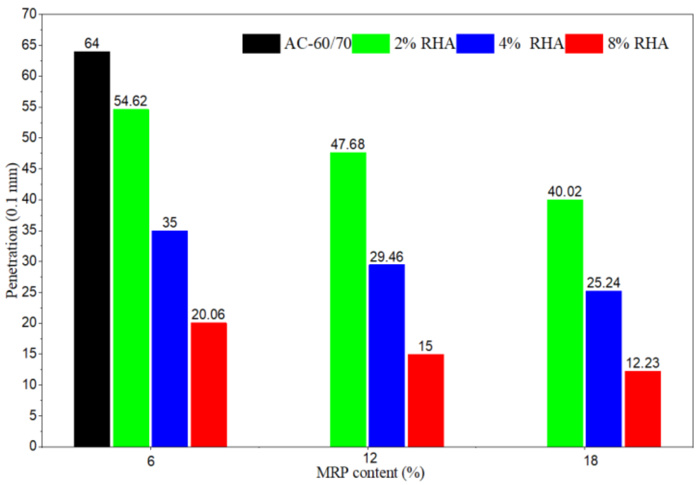


Figure 4: RHA & MRP concentrations' impact on the penetration.

3.2. Softening point

Figure 5, displays softening point worth gained from the modified and neat binders. It is noted that the softening point values increased clearly and invariably due to the increase in the mass concentration of RHA and MRP. The neat asphalt softening point values increased by 22%, 29% and 39% when used 4% RHA with 6%, 12% and 18% MRP respectively. The softening point of adjusted asphalts increased as temperatures rise, and as a result the ability to permanently deform decreases, and thus the perfect execution of rutting may acquire through employing these types of modified bitumen binders to outfit asphalt blends (Arabani & Tahami, 2017). Higher softening points in RHA and MRP-modified asphalt binders indicate improved high-temperature performance, which means increased resistance to rutting and deformation under heavy loads and heat. This modification leads to a more durable asphalt binder with a longer service life, especially in warmer climates. However, a high softening point can make the binder more brittle at cold temperatures, potentially increasing susceptibility to thermal cracking.

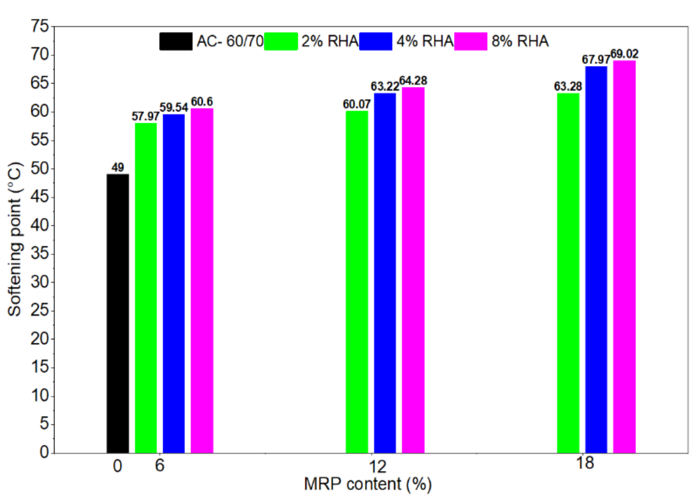


Figure 5: Effects of RHA and MRP content on softening point.

3.3. Penetration index

PI utilized as an indicator of temperature susceptibility (Newtonian viscosity ratio at 25°C and 60°C is known as temperature sensitivity. The value of PI ranging from −3 to +7 as explored in Figure 6, which means that if the PI is low, then the asphalt is classified as highly sensitive to high temperatures. On the other hand, if the PI is high, then the asphalt is classified as low sensitive to high temperatures(J. Read & Whiteoak, 2003). To obtain better estimates of predictable temperature sensitivity rendering of asphalts, PI was used. PI is calculated from the penetration and softening point values using the formula (2) (J. Read & Whiteoak, 2003).

$$PI = \frac{20T_{R\&B} + 500 \times \log(Pen_{25}) - 1952}{T_{R\&B} - 50 \times \log(Pen_{25}) + 120} \quad (2)$$

Where:

Pen_{25} is asphalt penetration at 25 °C, $T_{R\&B}$ is the softening point. According to PI values, PI has been shown a rise as the RHA and MRP content increased. Thus, the height in RHA and MRP contents mass led to the reduction in temperature susceptibility (Galooyak, Dabir, Nazarbeygi, & Moeini, 2010). In MRP and RHA modified asphalt binders, the penetration indicator value is a measurement of temperature susceptibility. A higher PI value pointed that adjusted binder is minimal sensitive to heating alteration and exhibits improved overall performance, particularly in terms of impedance to perpetual deformation (rutting) at elevated temperatures, better aging resistance, and depressed temperature cracking.

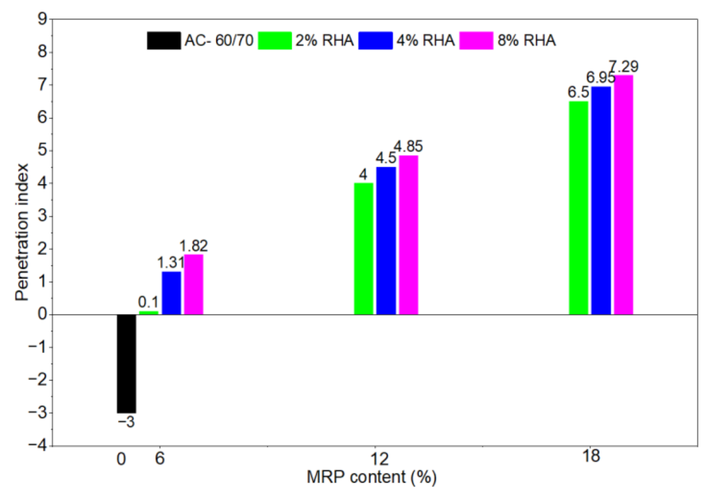


Figure 6: Shows the impact of the penetration index due to the addition of RHA and MRP.

3.4. Elastic recovery (ER)

ER values of the neat as well as amended binders are revealed in Figure 7, and it is noticeable that the variation within elastic recovery due to varied MRP and RHA contents showed a climb in elastic recovery values for all adjusted specimens. Elastic recovery varies from 40.4% when used 2% RHA with 6% MRP to 72.3% when used 8% RHA with 18% MRP (Liu, Fu, Jiao, Tao, & Wang, 2017). The high elastic recovery of micronized rubber modifier powder (MRP) and rice husk ash (RHA) amended bitumen binders leads to enhanced pavement strength and improved reluctance to fatigue cracking and rutting.

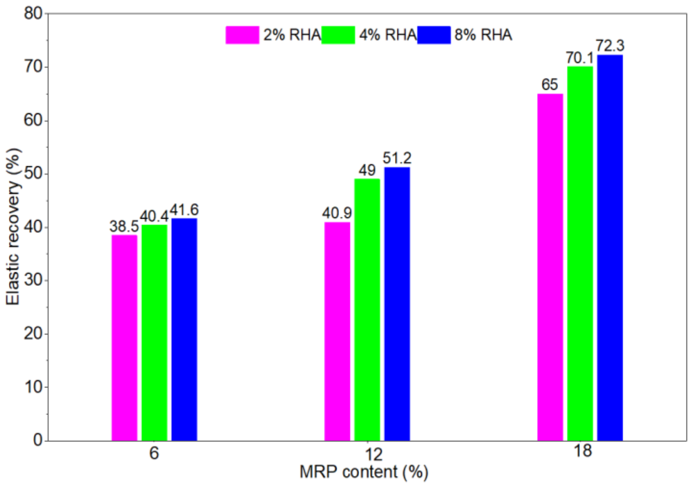


Figure 7: Impact of MRP and RHA on elastic recovery.

3.5. Rotational viscosity

The rotational viscometer applied to evaluate workability of modified asphalt binders at temperatures of 135 ºC as shown in Figure 8. Outcomes demonstrated that the viscosity goes up by augmentation of MRP and RHA contents, giving perfect signal of leverage of MRP and RHA on asphalts' elevated temperature rendering. Consequences specified by Figure 8 demonstrated that the amounts more than 3.0 Pa.s when 2%, 4%, and 8% RHA used with 18% MRP respectively, therefore a suitable increase of temperature is needed to improve their workability according to strategic highway research program (SHRP) specifications which says, the viscosity at 135 °C must be less than 3.0 Pa.s because elevated viscosity could leading to cause difficulties linked with workability.

The effect of micronized rubber modifier powder (MRP) and rice husk ash (RHA) represent in increased viscosity because the addendum of MRP significantly boost the viscosity of the bitumen binder at high temperatures. This is primarily due to the sucking of maltenes by the rubber particles, causing them to swell and form a viscous gel network. In temperature and content dependence, the viscosity increases with higher RHA and MRP content and longer mixing times.

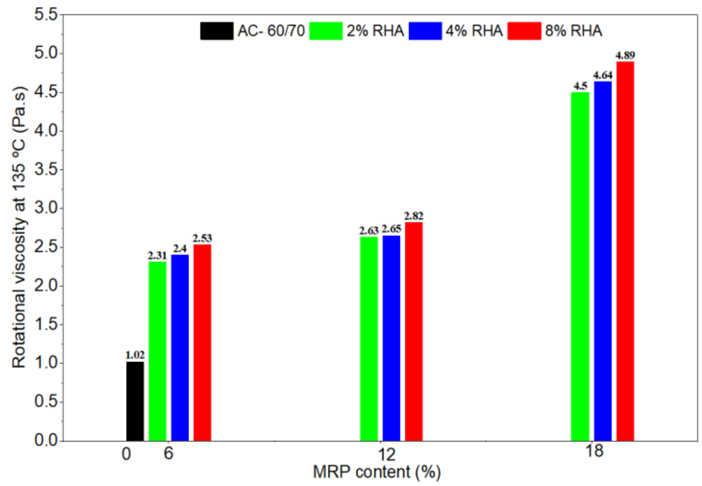


Figure 8: Action of MRP and RHA on rotational viscosity.

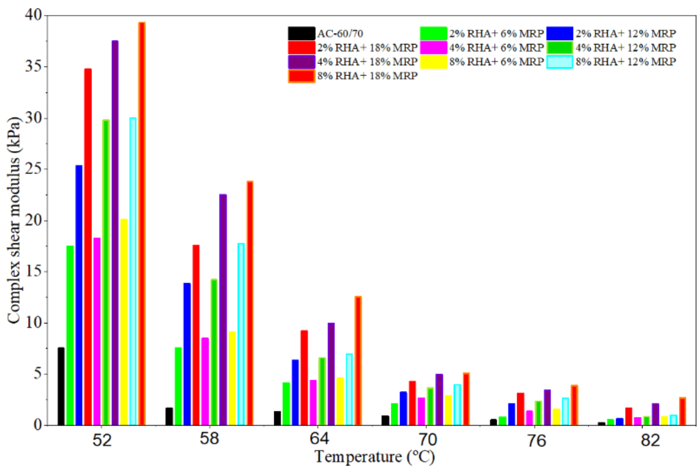
3.6. Complex shear modulus and phase angle

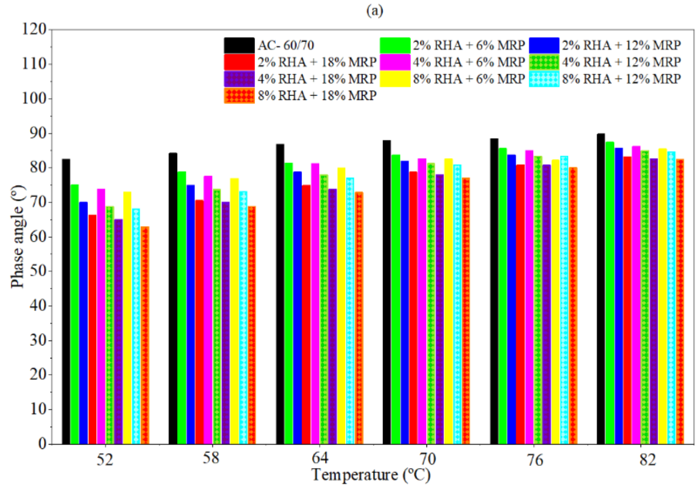
The alteration in viscoelastic properties of asphalt is a very important factor when combining modifiers due to the strong interaction amidst the modulus of elasticity and rutting resistance at elevated temperatures. Complex shear modulus and phase angle were applied here to characterized viscoelastic attributes of bitumen materials. In asphalt rheology, phase angle (δ) defined as a measure of material's viscoelastic properties, specifically time difference among the utilized stress and the produced strain. Generality real-world materials are viscoelastic, presenting characteristics of both resilient solids and viscous liquids. Their phase angles limited thereabout between 0° to 90°, marking an integration of energy storage and dispersion ("The Asphalt Institute. Performance graded asphalt binder specification and testing, SP-1. Lexington (KY): The Asphalt Institute; 2003.,").

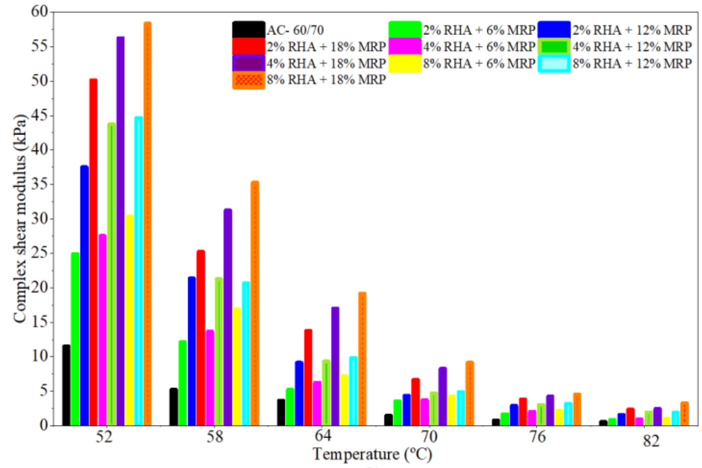
Complex shear modulus and phase angle of AC 60/70 and adjusted asphalt binders (before and next the RTFO aging) are represented through Figure 9 (a, and b). As listed in Figure 9 (a), complex shear modulus reduced largely with boost of temperatures consequent to reality that growing in temperature led to increase the bias of bitumen binder to stream and influence asphalt binder resistance to rutting. The reduced complex shear modulus (G*) in modified asphalt indicates a reduction in material's hardness and rising its flexibility and viscous behavior. This has several key effects on performance such as improved fatigue cracking resistance.

Can be found in Figure 9 (a) that the increase in mass of MRP and RHA make the complex shear modulus going up. The AC 60/70 had the less shear modulus comparing with amended asphalt binders. The high value shear modulus indicates that the adjusted bitumen binders are more solid than the AC 60/70. On the contrary, the phase angle went up together with temperatures raised and decreased with MRP and RHA concentrations increased. Figure 9 (a) suggested that the modified asphalt binders using RHA and MRP at high-temperatures shown perfect flexible attitude comparing to AC 60/70, which expected to have a best influences on the behavior of amended hot mix asphalt patterns under loading.

From Figure 9 (b) next RTFO, complex shear modulus of AC-60/70 increased by twice of that prior aging. The amount of G* increased next the addition of RHA and MRP, on the contrary, phase angle was dropped, which decreased about ten degrees after adding 2% RHA with 6% MRP. The raise in shear modulus value signalizes that rice husk ash and MRP had stiffening impacts on the asphalts, in contrast, reduced phase angle amount give the indicator of elevated elasticity. After aging, bitumen toughness and high temperature performance increased, therefore addition of rice husk ash and MRP affect positively through amending the aging reluctance of asphalt binder.







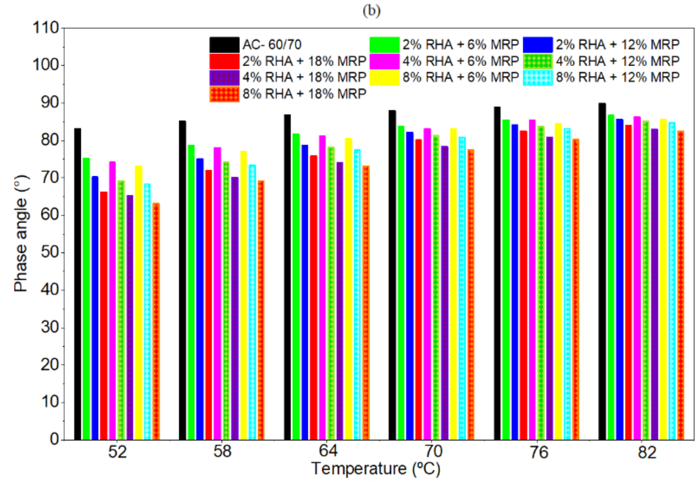


Figure 9: Impact of rice husk ash & MRP on G* andδ: (a) prior aging and (b) next aging.

3.7. Rutting resistance parameter

The rutting parameter (G*/sin (δ)) is usually applied to straighten the resistant versus perpetual distortion for bitumen binders at elevated temperatures. Following the Superpave methods (AASHTO M 320), the G*/sin(δ) values should be at lowest value as 1.0 k Pa for the bituminous materials prior to aging and about 2.2 k Pa next aging ("The Asphalt Institute. Performance graded asphalt binder specification and testing, SP-1. Lexington (KY): The Asphalt Institute; 2003.,"). Figure 10 (a, and b) illustrates value of G*/sin (δ) with various temperatures.

It is obvious through Figure 10 (a) that the value of rutting parameter raises with adding RHA and MRP comparing with AC-60/70. Also, the magnitude of (G*/sin (δ)) show significantly increase with high content mass of RHA and MRP. Can be identified in Figure10 (b) similar trends for all amended asphalt samples. Moreover, rutting parameter values declined with increase of the temperature prior to aging as well as after aging. It is derived that RHA and MRP addition has a high impact in enhancement impedances of asphalt binder specimens to the rutting distress.

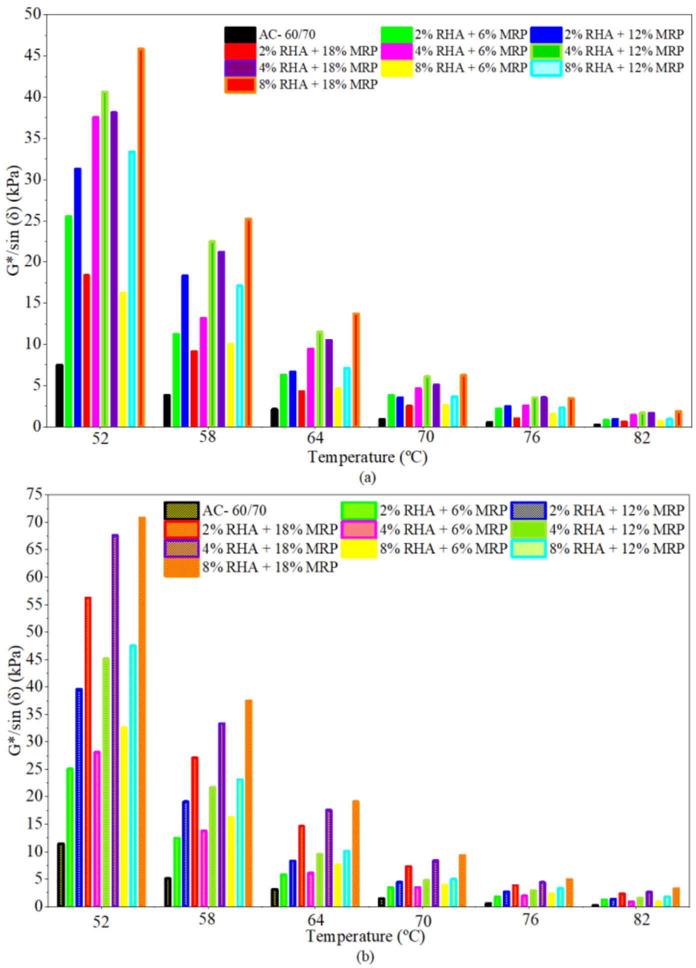


Figure 10: Impact of RHA and MRP on rutting parameter: (a) prior aging, (b) next RTFO aging.

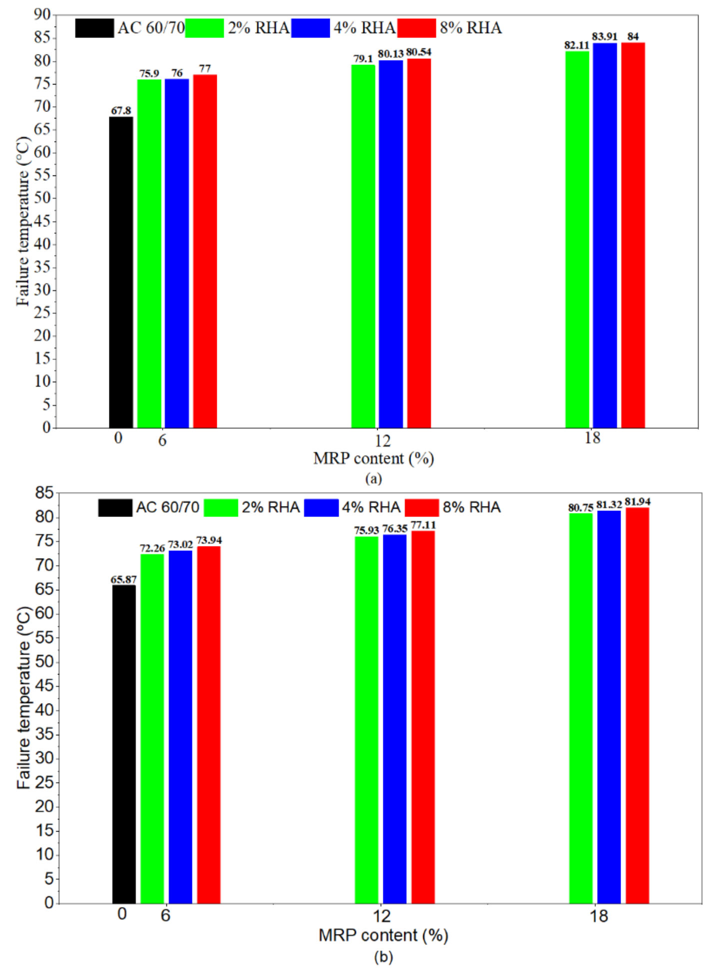


Figure 11: Influence of RHA&MRP: (a) before aging and (b) after RTFO on fail temperatures.

3.8. Fail temperature

PG of bitumen is frequently achieved via the fail temperature which refers to specific temperature identical to the amount of the rutting parameter (G*/sinδ), when G*/sinδ values are lower than 1.0 k Pa and 2.2 k Pa before and after aging respectively ("E. Harrigan R. Leahy J. Youtcheff Superpave manual of specifications, test methods and practices, SHRP-A-379 1994 Strategic Highway Research Program National Research Council, Washington, DC.,"). Figure 11 a & b illustrated the failure temperatures before and after RTFO aging respectively when different concentration masses of MRP and RHA were added.

As showed in Figure 11 (a), it can be clearly noticed that the fail temperature raised with addendum of RHA and MRP concentricity, hence the addition of 2% RAH with 6%,12% and 18% MRP made the failure temperature of AC-60/70 raised from 67.8 °C to 75.9 °C, 79.8 °C, and 83.3 °C. Inspection of Figure 11 (b) referenced that failure temperatures after RTFO aging had a lower orientation to increase together with the increase of RHA and MRP, which lead to improve the PG-temperature grade. Increments of RHA and MRP contents made ingredients at A-60/70 PG which climb from PG64-xx to PG76-xx when 8% RAH used with 18% MRP.

3.9. Wheel tracking test-rut depth

The rut depth values are explained in Figure 12, it is observed that the rut depth amount in the micronized rubber powder and rice husk ash modifier mixtures were quite less than amounts of unmodified asphalt mixtures which range from 4.352-5.469 mm. By considering the dynamic stability (DS) amounts of modified mixtures see Figure 13, which are acts as the figure of the cycles required to output 1 mm of rut depth in the duration of the experimental time in the domain between 45 and 60 minutes. When utilized 2% RHA with 6% MRP, 4% RHA with 12% MRP, and 8% RHA with 18% MRP the results are 2453.76, 4181.175, and 4230 cycle/mm respectively. It is seen that DS increased with modifier percentage growing.

In rapprochement between modified asphalt mixtures utilizing 2% RHA with 6% MRP, 4% RHA with 12% MRP, and 8% RHA with 18% MRP, the dynamic stability of specimen of 8% RHA with 18% MRP is superior to the specimens applied 2% RHA/6% MRP and 4% RHA/12% MRP which means that the 8% RHA/18% MRP has a lower rut depth (RD). The effectiveness of RHA/MRP modification on rutting impedance is thus more considerable. Furthermore, it was noticed that the modified asphalt mixtures achieved the more resistance to the permanent deformation (rutting). It is of attention to know that the RHA/MRP modified mixtures had the preferable derivation in the wheel tracking test and the better permanent deformation behavior. Thus, RHA/MRP employment progressed the mechanical characteristics considerably.

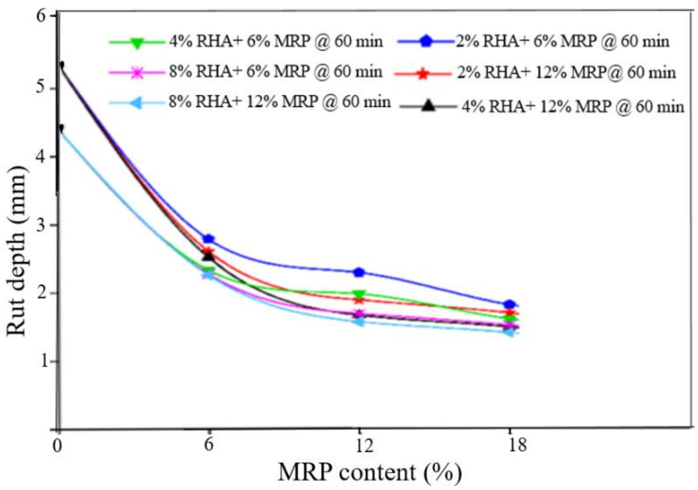


Figure 12: Rut depths of RHA / MRP modified mixtures.

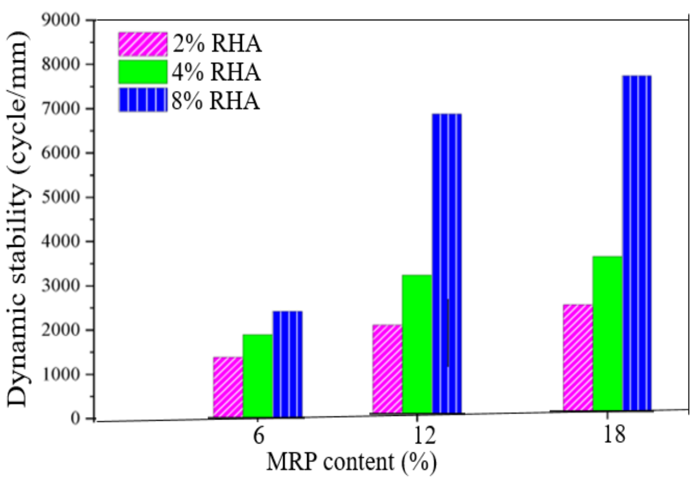


Figure 13: DS obtained from the RHA/MRP-modified bitumen mixtures.

4. Conclusions

The research objectives are to test the influence of combining RHA and MRP on the mechanical, physical, and rheological properties of asphalt binders at elevated temperatures through diversified experimental tests. Furthermore, RTFOT test was achieved on the neat and modified binders to test the aging behaviors. To our knowledge, the previous researches have not addressed the physical and mechanical characteristics simultaneously to examine the effect of improving asphalt binders and mixtures by utilizing RHA and MRP. Based on outputs of the current study, the next epilogue can be summarized:

1. The alterations on characteristics of bitumen binder modified with rice husk ash (RHA) and micronized rubber powder (MRP) specifically a reduction on penetration, raise on softening point, boost on viscosity, and increase on penetration index (PI) indicate significant improvements in the binder's performance characteristics, primarily enhancing its resistance to distresses such as rutting. However, suggesting that the asphalt binder hardness was increased which improved its resistance to temperature susceptibility.
2. Elastic recovery generally increased as MRP and RHA content increased. The augmentation in elastic recovery of RHA and MRP modified bitumen primarily indicates enhanced elasticity and perfected performance characteristics, specifically the impedance to permanent deformation (rutting) and fatigue or temperature cracking.
3. The MRP and RHA amended binders displayed an elevated complex modulus (G*) and less phase angle (δ). The raise in complex modulus (G*) and lower in phase angle (δ) in RHA/MRP modified binders indicated to enhance stiffness and elasticity, leading to improved high-temperature performance and increased resistance to permanent deformation.
4. After the RTFO, the bitumen binder toughness increased as well as the elevated-temperature performance. An increase in the asphalt rigidity and elevated temperature performance after RTFO aging in RHA and MRP-modified asphalt results in the huge favorable effects like the rutting resistance. The primary effect of increased hardness and high-temperature performance (indicated by an increment in G*, and rutting parameter (G*/sin δ)) is a significant enhancement in the modified bituminous capability to withstand perpetual deformation (rutting) under high service temperatures. RHA and MRP created a reinforcing network that increases the binder's rigidity and elastic properties.
5. Enhancing the performance grade (PG) of MRP and RHA modified binders primarily affects its high-temperatures stiffness and low-temperatures flexibility, leading to amended resistance to rutting and cracking, respectively.
6. The gained values of the rut depth (RD) are the least amount in the 8% RHA/ 18% MRP mixtures than other concentrations. The preferable refinement of the mechanical properties and execution of the RHA and MRP modulated mixtures were observed in 8% RHA/18% MRP concentrations. Hence, 8% RHA/18% MRP-modified mixtures displayed superior high-temperature performance followed by another percentages. Moreover, the RHA and MRP can progress the high-temperature rutting-withstand peculiarity of the bitumen binders and mixtures. Likewise, 8% RHA/18% MRP modified bitumen mixtures had the perfect consequence in WTT and superior permanent deformation attitude.
7. In rapprochement between modified mixtures, the dynamic stability (DS) of specimen of 8% RHA with 18% MRP is superior to the specimens applied another contents which means that the 8% RHA/18% MRP has a higher DS.

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Declaration of conflict of interest

The authors have no conflict of interest. The authors have collectively contributed to the conceptualization, design, and execution of this research paper. They have worked on drafting and critically revising the article to include significant speculative content. This manuscript has not been previously submitted or reviewed by any other journal or publishing platform. Additionally, the authors do not have any affiliation with any organization that has a direct or indirect financial stake in the subject matter discussed in this manuscript.

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