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Research Article

Utilization of Rice Husk Ash and Waste Engine Oil as Sustainable Modifiers for Asphalt Binder

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Abstract **–** Improper disposal of significant quantities of waste materials, such as Rice Husk Ash (RHA) and Waste Engine Oil (WEO), poses a significant environmental risk through water and air pollution. Moreover, the limited availability of disposal space adds to the concerns surrounding their safe management. However, an alternative approach involves incorporating these waste materials as additives in asphalt binder, offering not only improved binder properties but also a means to address environmental issues. This study focuses on the modification of the binder by introducing different proportions (2%, 4%, and 6%) of Rice Husk Ash with Waste Engine Oil (2% and 4%). Through a range of tests, including conventional tests, the Bitumen Bond Strength test, Rolling Bottle test, and multiple stress creep recovery test, the modified binder specimens were evaluated for adhesion, moisture susceptibility, and elastic recovery. The experimental findings highlight that a bitumen mixture consisting of 6% Rice Husk Ash and 2% Waste Engine Oil, relative to the binder's weight, demonstrates superior adhesion, moisture susceptibility, and elastic recovery compared to the original binder. This innovative approach offers a sustainable and environmentally friendly solution for reusing Rice Husk Ash and Waste Engine Oil.

Keywords – Agricultural Waste, Rice Husk Ash, Asphalt, Neat Binder, Waste Engine Oil

I. INTRODUCTION

Hot mix asphalt has been extensively utilized worldwide for flexible pavement construction. However, the use of traditional job mix formulas for hot mix asphalt often leads to the emergence of various stress-related issues such as rutting, moisture damage, and fatigue cracking [1], [2]. These problems typically arise due to factors like overloading, climate conditions, and extreme temperatures. To address these stress-related concerns, modifying the neat asphalt binder is considered the most suitable approach [3]. Various types of binder modifications have been employed to mitigate rutting, fatigue, and moisture damage. However, the current practice of disposing waste materials in landfills has become a significant issue due to limited land availability and its detrimental effects on the environment [4], [5].

The agricultural industry generates a substantial amount of waste during crop harvesting [6]. This waste mainly comprises husks and straws from plants and crops. The production of large quantities of industrial waste materials presents severe environmental challenges that parallel those associated with landfills [7]. Typically, factories and plants use the energy produced by burning agricultural waste [8]. According to data from the Food and Agriculture Organization (FAO), global annual rice production stands at 7.82E+08 tonnes, while wheat production amounts to 7.34E+08 tonnes. Approximately 200 kg of rice husk is generated per tonne of rice, and each tonne of wheat grain produces over 1300–1400 kg of wheat straws [9], [10]. Arabani and Tahami investigated the mechanical properties of asphalt binder modified with rice husk ash (RHA) and confirmed that the addition of RHA significantly affects rutting and fatigue behavior [8]. Similarly, Sargn et al. noted RHA serves as a favourable filler for asphalt mixtures, and they came to the conclusion that a mixture containing 50% RHA and 50% limestone filler yields the most favourable results in enhancing Marshall's stability and flow [11]. Xue et al. also demonstrated that incorporating RHA as an additive in asphalt binder improves its physical properties. Furthermore, their analysis using FT-IR spectroscopy indicated the absence of any chemical reaction between the asphalt binder and RHA [12]. In their research, Zaidi et al. conducted a systematic analysis of the moisture damage caused by high levels of liquid asphalt in asphalt mixtures and bitumen mastic. Through tests such as the Rolling Bottle test and Bitumen Bond Strength test, they observed that modified-HL asphalt concrete exhibits enhanced adhesion and resistance to moisture damage [13].

Significant amounts of RHA are dumped in landfills, worsening the situation of scarce land, while WEO is carelessly dumped in rivers and on land, endangering drinking water supplies, ecosystems, and human health. The use of these byproducts in neat asphalt binder not only contributes to solving these environmental problems, but also improves the mixture's durability. As a result, the overall goal of this research is to find a sustainable way to dispose of waste by evaluating combining RHA with WEO affects the properties of bitumen.

II. Experimental and Research Methodology

Bitumen of the 60-70 Pen grade was used in this research, and it is widely available in Pakistan. The aggregates are sourced from Margalla quarries. RHA is obtained as ash from brick kilns, while Waste Engine Oil (WEO) is collected from local auto repair shops. The modified neat binder is prepared by incorporating a specific weight percentage of RHA, WEO, and the neat binder. To ensure proper homogeneity, a high shear mixer operating at 1500 rpm is employed. The mixing process is carried out for 40 minutes at a temperature of 160°C. The impact of RHA and WEO on the neat binder's properties is assessed through various tests, including penetration, softening point, ductility, and rotational viscometer tests, in accordance with ASTM standards D5 [14], D36 [15], D113-99 [16], AASHTO TP4 [17] respectively.

The Bitumen Bond Strength (BBS) test is conducted using the Pneumatic Adhesion Tensile Testing Instrument (PATTI) in accordance with ASTM standard D4541 to determine the adhesion of the bitumen and aggregates in both dry and wet circumstances. [18]. Sample preparation involves heating the bitumen binder and sandstone aggregates to 140°C to ensure proper bonding.

Moisture susceptibility is investigated using the Rolling Bottle Test (RBT) according to BS EN 12697-11 [19]. Sample preparation require mixing 170g of aggregate with 8g of bitumen. The bitumen coating on the samples is observed after rolling for different durations (6, 24, 48, and 72 hours). To assess the elastic behavior and recovery, the Multiple Stress Creep Recovery Test is conducted by applying a load for 1 second and removing it for 9 seconds, with each second comprising 10 cycles. Elastic recovery is evaluated based on ASTM standard D7405-20 [20].

The research methodology employed in this study is visually represented in Figures 1 and 2.

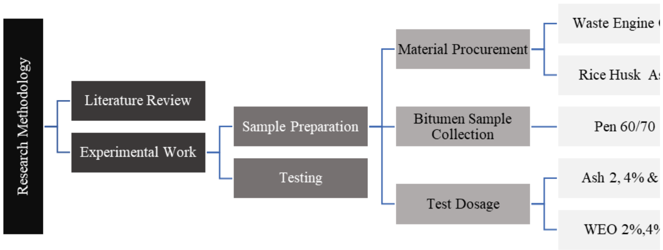

Fig 1. Research Methodology

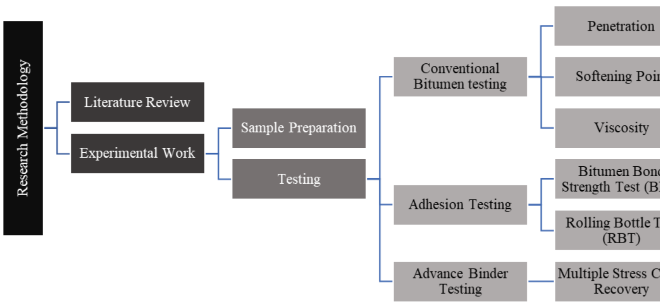

Fig 2. Research Methodology

III. RESULTS AND DISCUSSION

A. *Conventional Testing*

The objective of this research was to analyze the influence of rice husk ash (RHA) and waste engine oil (WEO) on conventional bitumen. The primary focus was on conducting penetration, softening point, and viscosity tests to determine the modified binder's hardness, softness, and viscosity. These properties play a crucial role in assessing moisture damage and adhesion. The experimental results obtained from the conventional testing are presented in Figure 3. The addition of 6% RHA and 2% WEO by weight of the neat binder in the 60-70 pen bitumen led to a 17% reduction in penetration value, while the softening point increased by 13% compared to the neat binder.

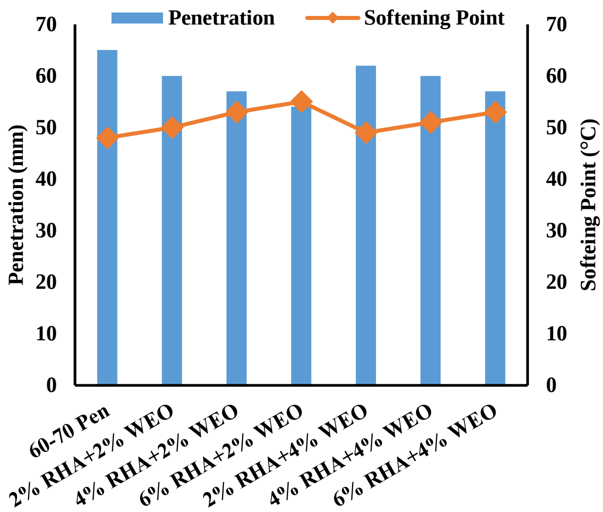

Fig 3. Penetration and softening point values of modified and unmodified bitumen with a penetration grade of 60-70.

The rotational viscometer (RV) test was conducted at a temperature of 135°C on all combinations of modified binder and the virgin binder. As the percentage of rice husk ash (RHA) increased from 2% to 6% while maintaining a constant 2% waste engine oil (WEO) content, the viscosity of the modified binder increased from 210 Cps to 249 Cps, showing a 15% increase. The viscosity values for the different combinations can be observed in Figure 4.

Consequently, as the RHA dosage in WEO increased, the penetration values decreased, indicating a harder binder. Additionally, the viscosity values increased, and the softening point rose. This implies that incorporating RHA into WEO in the 60-70 pen bitumen formulation resulted in a binder with enhanced hardness.

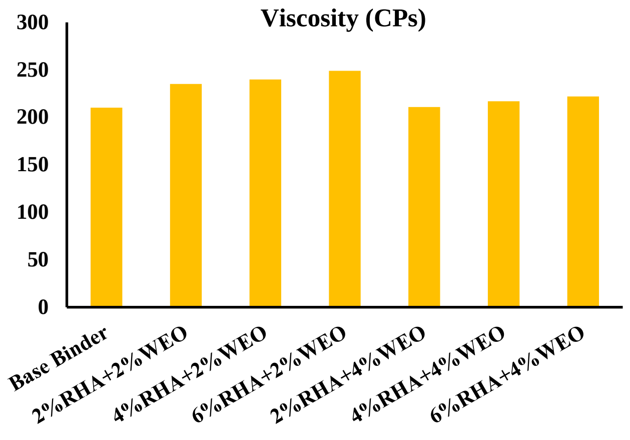

Fig 4. Viscosity values of modified and unmodified bitumen with a penetration grade of 60-70

B. Analysis of adhesion using BBS test.

The experimental investigation focused on examining the influence of combining rice husk ash (RHA) and waste engine oil (WEO) on the adhesion properties of the neat binder. To measure the adhesion between the bitumen and aggregate, the Pneumatic Adhesion Tensile Testing Instrument (PATTI) was utilized. This test is essential for assessing the force required for separation. Various combinations of RHA (2%, 4%, 6%) and WEO (2%, 4%) were incorporated into the neat binder by weight to evaluate the bond strength between the bitumen and aggregate. The burst pressure, which signifies the point of stud detachment from the aggregate sample, was determined using PATTI. This information was then used in equation 1 to calculate the Pull Off Tensile Strength (POTS).

$$POTS = \frac{(BP * A_g) - C}{A_{ps}} \qquad (1)$$

Where:

POTS represents the pull-off tensile strength

BP indicates the burst pressure

A_g represents the contact area (2620 mm^2)

C is the piston constant (0.286)

A_{ps} is the area of the pull-stub (127 mm^2)

F-4 stub type was used in this study.

In the case of 60-70 pen grade bitumen, the addition of 6% RHA + 2% WEO and 6% RHA + 4% WEO by weight of the binder led to increases of 55% and 48%, respectively, in POTS values compared to the neat binder under dry conditions.

After subjecting the samples to 24, 48, and 72 hours of wet conditioning, the POTS values for the 6% RHA + 2% WEO and 6% RHA + 4% WEO combinations decreased, yet remained higher than those of the neat binder. This decline can be attributed to the penetration of water at the bitumen-aggregate interface and the bitumen-bitumen interface, resulting in a weakening of the bond between them.

In dry conditions, the modified binder with 6% RHA + 2% WEO demonstrated superior POTS values compared to the neat binder and other combinations. However, the modified binder with 4% WEO in combination with RHA exhibited lower POTS values compared to the combinations with 2% WEO, both in dry and wet conditions. Nevertheless, these values still showed improvement when compared to the control binder.

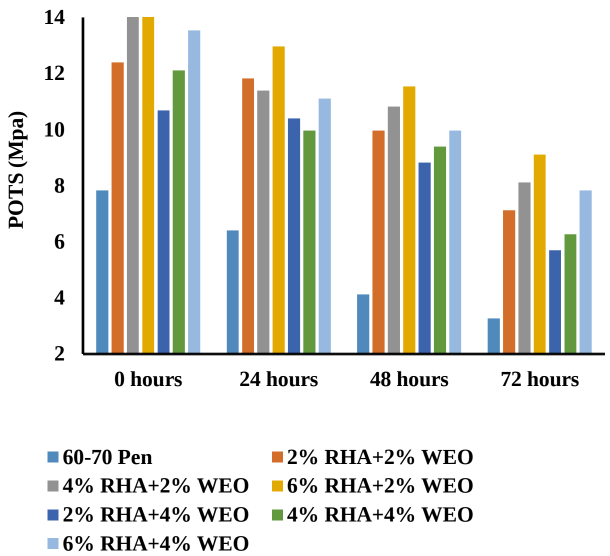

Fig 5. POTS values of modified and unmodified bitumen with 60-70 penetration grade in dry and wet conditions.

C. Failure surface analysis.

There are two types of failures when stubs detach from the aggregate surface: cohesive failure and adhesive failure. The type of failure can be determined by examining the amount of bitumen remaining on the aggregate sample. If more than 50% of the bitumen is still present, it indicates cohesive failure. Conversely, if less than 50% of the bitumen remains, it indicates adhesive failure. When approximately 50% of the bitumen is observed on the aggregate, it signifies cohesive adhesive failure.

Table 1 displays the percentage coverage of bitumen and the corresponding failure type after subjecting the samples to both dry and wet conditioning. When 60-70 penetration grade bitumen was modified with Rice Husk Ash +2% Waste Engine Oil, a higher binding strength was achieved, and the failure mode shifted from cohesive to adhesive after 48 hours of water conditioning. On the other hand, Rice Husk Ash +4% Waste Engine Oil-modified 60-70 penetration grade bitumen showed that failure mode shifted from cohesive to adhesive after 24 hours of wet conditioning.

Table 1. Percentage of bitumen and failure type after dry and wet conditioning

CT*	60-70 Pen	2%RHA+2 %WEO	4%RHA+2 %WEO	6%RHA+2 %WEO	2%RHA+4 %WEO	4%RHA+4 %WEO	6%RHA+4 %WEO
0 hrs.	67C	71C	74C	85C	69C	72C	77C
24 hrs.	48A	68C	71C	79C	66C	69C	71C
48 hrs.	39A	65C	68C	71C	46A	48.5A	50C/A
72 hrs.	29A	33A	39A	44A	31A	36A	39A

CT* curing time; A, adhesive failure; C, cohesive failure; C/A, 50% adhesive 50% cohesive failure

D. *Moisture damage evaluation using RBT*

In order to evaluate the affinity and bonding between bitumen and aggregate, a rolling bottle test was conducted as part of the experimental analysis. The objective was to assess the adhesion properties of the modified asphalt mixture compared to the neat asphalt mixture. The results, depicted in Figure 6, provide valuable insights into the effect of incorporating Rice Husk Ash (RHA) in combination with Waste Engine Oil (WEO) on the adhesion performance.

The findings from the rolling bottle test indicate a notable trend: as the rolling time increased, the bitumen coverage values exhibited a decreasing pattern. This suggests that the longer the rolling time, the lower the coverage of bitumen on the aggregate surface. This phenomenon can be attributed to various factors such as the displacement of bitumen during the rolling process or the interaction between the bitumen and the aggregate particles.

Importantly, the modified asphalt mixture containing RHA in WEO showcased enhanced adhesion characteristics when compared to the neat asphalt mixture. After 72 hours of rolling time, the 6% RHA + 2% WEO modified asphalt mixture exhibited a significant 40% increase in bitumen coverage, indicating improved bonding between the bitumen and the aggregate. Similarly, the 6% RHA + 4% WEO combination displayed a notable 25% increase in coverage compared to the neat asphalt mixture.

The adhesion effect of the 6% RHA + 2% WEO modified asphalt mixture, specifically in the case of 60-70 pen grade asphalt mixture, was particularly prominent. This suggests that this specific combination of RHA and WEO had a significant impact on enhancing the adhesion properties of the modified asphalt mixture, leading to improved bonding between the bitumen and the aggregate particles.

These findings highlight the potential of using RHA and WEO as additives in bitumen modification, as they offer promising results in terms of enhancing adhesion performance. The improved adhesion between bitumen and aggregate is crucial for ensuring the durability and longevity of asphalt pavements, as it helps to resist the detrimental effects of traffic loads, moisture ingress, and other environmental factors.

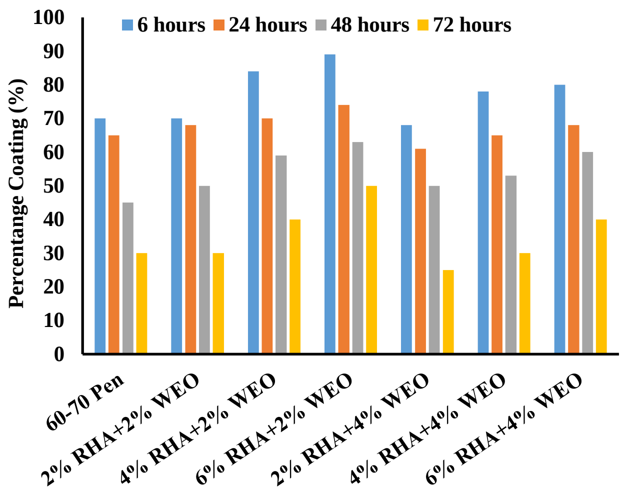

Fig 6. Comparison of bitumen coverage for modified and unmodified bitumen at various time durations.

E. *Multiple Stress Creep Recovery Test*

The study focused on analysing the behaviour of RHA and WEO modified asphalt binders in terms of creep recovery. The MSCR test was conducted at different temperatures (58°C, 64°C, and 70°C) to investigate the impact of various stress levels on the J_{nr} values of the asphalt binder, specifically at 70°C to align with the desired performance grade of PG-70. The results revealed that as the stress levels increased, the J_{nr} values also increased up to a maximum of 26.5Kpa. Interestingly, the neat binder exhibited the highest J_{nr} value, while the 6% RHA+2% WEO combination demonstrated the lowest J_{nr} value, indicating superior elastic recovery characteristics. Figure 7 provides a visual representation of these findings.

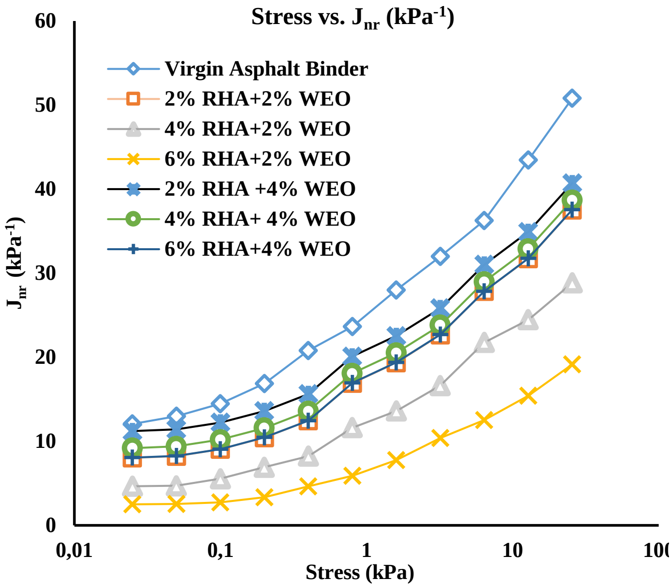

Fig 7. Impact of stress level on J_{nr} values of modified and unmodified binder at a temperature of 70°C.

IV. CONCLUSION

The findings derived from research study can be summarized as follows:

• The utilization of waste engine oil and biomass ash in asphalt binder and mixture offers significant environmental benefits and helps address land use concerns.

• Among the various combinations studied, the addition of 6% RHA + 2% WEO to the neat binder resulted in the lowest penetration value and the highest softening point value. Specifically, the penetration value decreased by 17%, while the softening point increased by 13%.

• The RV test revealed that all modified binder percentages exhibited improved viscosity behaviour compared to the neat binder, with the 6% RHA + 2% WEO combination demonstrating the most favourable performance.

• Incorporating 6% RHA + 2% WEO into the neat binder led to a substantial 55% increase in Pull Off Tensile Strength (POTS) under dry conditions, surpassing the neat binder and other studied combinations. However, a decrease in POTS values was observed after 24, 48, and 72 hours of wet conditioning.

• The Rolling Bottle Test (RBT) results showed that the 6% RHA + 2% WEO combination exhibited superior performance after 72 hours compared to all other studied combinations.

• The 6% RHA + 2% WEO combination displayed the most favourable elastic recovery behaviour, as indicated by low J_{nr} values at all stress levels during the Multiple Stress Creep Recovery (MSCR) test.

In conclusion, based on the obtained results, it can be concluded that the combination of 6% RHA + 2% WEO yielded the most promising performance across the studied properties.

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