Performance Evaluation and Utilization of Bitumen with an Optimum Content of Various Agricultural Wastes

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Abstract. Every year, during energy production, a large amount of agricultural waste is generated as ash, such as husks from rice and wheat. The conventional practices of open dumping and landfilling of this ash cause severe environmental and health problems, particularly groundwater contamination. Moreover, a lack of space for further dumping or landfilling worsens the situation. Considering the difficulty of its disposal, as a solution, this research uses two different agricultural waste ash to improve the asphalt binder engineering properties. The study evaluates the optimum dosages of agricultural waste and assesses the economic benefits of using such modified bitumen in road construction. By integrating waste technology, this project proposes an innovative approach to enhance bitumen's conventional properties, durability, and sustainability in road construction. The investigation demonstrates that increasing the rice husk or wheat straw percentage in bitumen decreases its penetration value. However, the penetration value approaches the base bitumen when both waste materials are used together. The modified bitumen also exhibits higher softening points, making it suitable for higher temperature zones. Ductility decreases with the inclusion of agricultural waste, indicating that neat bitumen is better suited for high-temperature zones, while modified bitumen may be advantageous in low-temperature zones. The study emphasizes carefully selecting waste percentages to achieve desired bitumen properties. Future research should focus on optimizing the waste material mixture, conducting life cycle assessments, exploring large-scale implementation, and collaborating with industry stakeholders and policymakers to promote sustainable road construction practices.

Keywords: *Agricultural waste, rice husk, wheat straw, asphalt pavement, modified bitumen*

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1 Introduction

The construction of roads plays a vital role in driving economic development. Highways are crucial transportation routes, connecting urban areas and facilitating movement between urban and rural regions [1]. Transportation plays a vital role in reaching different destinations, and in Pakistan, various modes of transportation, such as highways, railways, and airways, are available [2]. However, the majority of transportation relies on highways. With continuous usage, these road pavements deteriorate over time, resulting in numerous problems and inconveniences for drivers.

The reutilization of waste materials in engineering has long represented a significant accomplishment for engineers [3]. A survey on biomass potential indicates that Pakistan generates approximately 82.12 million tonnes per year of crop residue. In 2021, the country produced 25 million tonnes of wheat and 10.8 million tonnes of rice. Agricultural activities contribute to a substantial volume of waste from harvested crops, with the primary agricultural waste products being rice husk, rice straw, sugarcane bagasse, sugarcane straw, wheat straw, and corn cobs.

According to data collected from the FAO report, the annual global production of rice, sugarcane, and wheat is approximately 782 Mt, 1900 Mt, and 734 Mt, respectively [4]. Additionally, straw is also generated as a residue. As mentioned earlier, the combustion of these crop residues produces significant agricultural waste ash (AWA), leading to environmental and landfill issues. As a result, researchers are now focusing on finding effective and sustainable methods for properly disposing of this harmful waste [4].

Recent research has investigated the feasibility of utilizing agricultural waste ash (AWA) derived from crop residues in concrete, with the objective of enhancing both mechanical and durability characteristics. Numerous experimental studies have documented the use of rice husk ash (RHA) and wheat straw ash (WSA) as pozzolanic materials. Moreover, issues related to design challenges, construction inefficiencies, reduced pavement lifespan, and distress caused by increasing traffic loads [5,6] have driven researchers to develop methodologies for assessing pavement performance and integrating recycled materials to enhance the properties of asphalt binders and mixtures [4]. In this context, AWA has also been explored as a potential modifier or additive for enhancing pavement performance. It has considerable enhanced both the rutting resistance and fatigue life [7].

These studies and investigations highlight the ongoing efforts to utilize AWA and incorporate recycled materials to enhance the properties and performance of concrete and asphalt pavements, aiming to achieve sustainable and durable transportation infrastructure. According to the study from [8], one ton of rice produces 200kg of rice husk [9]. Likewise, 1300-1400 kg of wheat straw is generated from one ton of wheat grain [10]. In this proposed project, agricultural wastes such as rice husk and wheat will replace binders in asphalt pavement. This research aims to improve the serviceability of pavements.

In asphalt construction, it is sometimes difficult to achieve quality bitumen structures when the materials used do not meet the necessary standards. Several common practices address this issue so the materials may behave as desired [11]. The main focus of this particular study is to improve the engineering properties of the asphalt binder. The modifier used in this study is agricultural waste. The waste is Rice Husk and Wheat Straw. These waste products are considered to have the potential to improve the performance of asphalt mixtures because of their distinctive properties and composition. The benefits of and the effective means for incorporating such agricultural waste into bituminous materials may be affected by such things as the type and dosage of the waste materials, the manufacturing processes, and the unique application needed for such products.

The incorrect disposal of solid agricultural waste has serious environmental consequences in many developing countries, as the residues can leach into water sources, causing water pollution and destroying aquatic ecosystems. Illegal dumping and burning of agricultural waste have equally serious environmental repercussions. It causes air pollution — affecting local people's health — and contaminates the soil (affecting its fertility and productivity). When the waste leaches into water sources, it further deteriorates water quality — killing aquatic life (and potentially impacting human communities' health).

Another significant concern related to agricultural waste disposal is the availability of dumping sites. With an ever-increasing volume of waste, finding appropriate locations for dumping that waste becomes difficult. The search for more land for dumping gives further impetus to finding alternative management methods to mitigate this challenge effectively. It is quite clear that negligent agricultural solid waste dumping and burning have severe environmental and health consequences. Air, water, and soil pollution, groundwater contamination, and reduced dumping land are harbingers of an urgent need for proper waste management and sustainable alternatives to alleviate these challenges.

The significance of this study is that there are many problems in Pakistan's agricultural sector. An annual output of 103 million tons is produced in Pakistan, containing significant agrarian waste. For instance, rice is grown at 200kg of rice husk per ton, and wheat grain is made at 1300–1400kg of wheat straw per ton. Unfortunately, most of these are dumped or burned, resulting in very adverse environmental effects. The main objective of this study is to form asphalt technology for recycling waste materials. The Major objectives are written as:

a. Assess the engineering performance of asphalt binder modified with agricultural wastes.
b. Ranking of agricultural waste based on conventional engineering properties.
c. Enhancement of construction economics.

2 Methodology

2.1 Agricultural Waste

In this study, the methodology employed focuses on utilizing agricultural waste, specifically Wheat Straw and Rice Husk, as modifiers to enhance the properties of bitumen. The chosen agricultural waste materials have been processed into micro-form by passing them through sieve no. 30. These waste materials were procured from Baluchistan.

Table 1: Physical Properties of Agriculture Waste

Property	Wheat Straw	Rice Husk
Composition	Cellulose, hemicellulose, lignin	Silica, cellulose, hemicellulose, lignin
Density (kg/m3)	40-200	130-170
Moisture Content (%)	10-15	12-15
Specific Gravity	0.25-0.4	0.15-0.25
Form	Micro	Micro and milli
Diameter (Sieve no 30)	0.6-12	0.25-0.6 mm
Softening Point (°C)	100-120	120-140
Penetration value (dmm)	3-8	1-5
Ductility (cm)	5-20	-

2.2 Bitumen

Bitumen of 60-70 grade was procured from Attock Refinery Limited (ARL). The obtained bitumen underwent standard tests to determine its properties.

3 Sample Preparation

An aluminum can and a high-shear homogenizer were employed to mix the bitumen with agricultural waste. The mixing process was carried out at a rate of 3000 rpm, as illustrated in Figure 1. Various ratios of bitumen and agricultural waste were utilized, as outlined in the following Table 2:

Table 2: Mixing Ratios of agriculture waste with bitumen

Waste	Ratio
Base Binder	0%
	2%
Rice Husk	4%
	6%
	2%
Wheat Straw	4%
	6%
Rice Husk and Wheat Straw	2% and 4%
Rice Husk and Wheat Straw	4% and 4%

Figure 1: Mixing of agricultural waste in bitumen.

3.1 Engineering Tests

Penetration tests were conducted in accordance with ASTM D 5 [12] to assess the influence of rice husk and wheat straw on bitumen stiffness. The bitumen was first heated in an oven until it reached a fluid state, after which it was poured into a container up to the required level. The container was then left to cool at room temperature for 40 minutes. The temperature of the water bath was maintained at 25 °C, and the container was fully submerged in the bath for 40 minutes. Following this, a needle was attached to a penetrometer, as depicted in Figure 2.

Figure 2: Penetrometer Test Apparatus

The container was removed from the water bath and placed on a penetrometer. A needle was lowered until its tip touched the container's top surface. Scale and time were adjusted by setting its value to zero and 5 seconds, respectively. The machine was run, and the reading was noted down.
The softening point, determined by ASTM D36, was measured at 54 °C. As illustrated in Figure 3, the ring and ball apparatus were used to determine the softening point of bitumen as per the ASTM D-36 standard [13].

Figure 3: Ring and Ball Test Apparatus

In the first stage, bitumen was heated around its conditioning point at 70 to 100 °C. The blend of glycerin and Dexedrine was set up on a glass plate and applied to the outer layer of glass to keep bitumen from staying. The ring was placed on the glass surface and covered with bitumen, allowing it to cool in the air for 30 minutes. The excess bitumen from the ring was eliminated from the upper part. The purified water in the measuring container was filled at 5°C. The container was filled to such an extent that its surface, around 50 millimeters, was over the sample. The ring and the ball guide were collected and put on the center plate of the metallic casing, leaving them for 15 minutes. The entire unit was placed on the heating plate at a temperature of 50 °C till the bitumen melted and came into contact with the lower part of the metal plate. The temperature was noted when the ball alongside bitumen contacted the lower plate.

Ductility tests were performed on the Ductilometer, as illustrated in Figure 4, to assess the effect of WEO and ECO on the tensile behavior and flexibility of bitumen, as per ASTM D 113 [14]. The same penetrometer procedure was used to fill and condition the

Ductilometer molds. The molds were immersed in a water bath for 40 minutes (the temperature should be 25 °C). The test was run by keeping its temperature at 25 °C, and the reading was noted when the bitumen thread started to break, or its diameter became thin.

Figure 4: Ductilometer Test Apparatus

4 Results and Discussions

4.1 Penetration Test Results.

Figure 5 analyses agricultural waste's impact on the bitumen's penetration value. The graph illustrates the relationship between the individual percentage of two types of agriculture waste, namely rice husk and wheat straw, and the resulting penetration value of the bitumen. From the graph, it is evident that an increase in the percentage of rice husk or wheat straw leads to a decrease in the penetration value of the bitumen when mixed with these waste materials. However, an interesting observation can be made when rice husk and wheat straw are utilized together. In this case, the penetration value approaches or matches the penetration value of the base binder. Notably, it demonstrates the highest penetration value, measuring 67mm, in contrast to the modified percentages achieved by incorporating agriculture waste, comparing the modified percentages to the base binder.

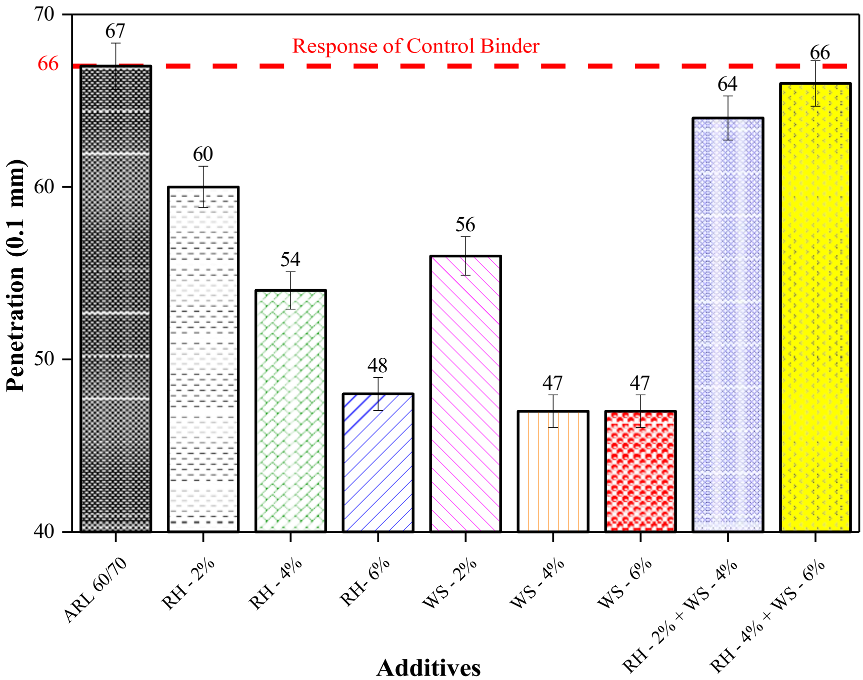

Figure 5: Effect of agricultural waste on Penetration values

According to the graph, including Rice Husk or Wheat straw in the binder makes it stronger and harder. They also make the binder more durable. This modified binder is more capable of resisting deformation under heavy traffic loads, which means it is better at resisting rutting. The graph shows that a hard binder with low penetration is ideal for hot areas. The additional hardness of the binder can bind the binder at higher temperatures, which means it will not rut. In cold regions, the better types of binder are binders that are softer with high penetration. They will be more flexible at the lower temperature. With this flexibility, cracking could be prevented.

4.2 Softening Point Test Results

The effect of rice husk and wheat straw percentage addition on the softening point of bitumen is demonstrated in Figure 6. It can be observed from this figure that as the ratio of agricultural waste increases, the value of the softening point also increases. This increasing trend of softening point values depicts that the softening of bitumen increases with the addition of a higher quantity of agricultural waste. As a result, the softening point value is the lowest for neat bitumen (48.2°C) and the highest for modified bitumen (55°C). This massive increase in the value of the softening point proves that a higher temperature reaches the softening point; consequently, bitumen is harder and stiffer. Hard bitumen with a high softening point is suitable for use where the temperature is at higher zones. Such kind of bitumen can withstand elevated temperatures and retain its stability. In contrast, cold bitumen with a lower softening point is more appropriate for cold climatic areas. The lower softening point of bitumen allows it to be flexible and resist cracking at lower temperatures.

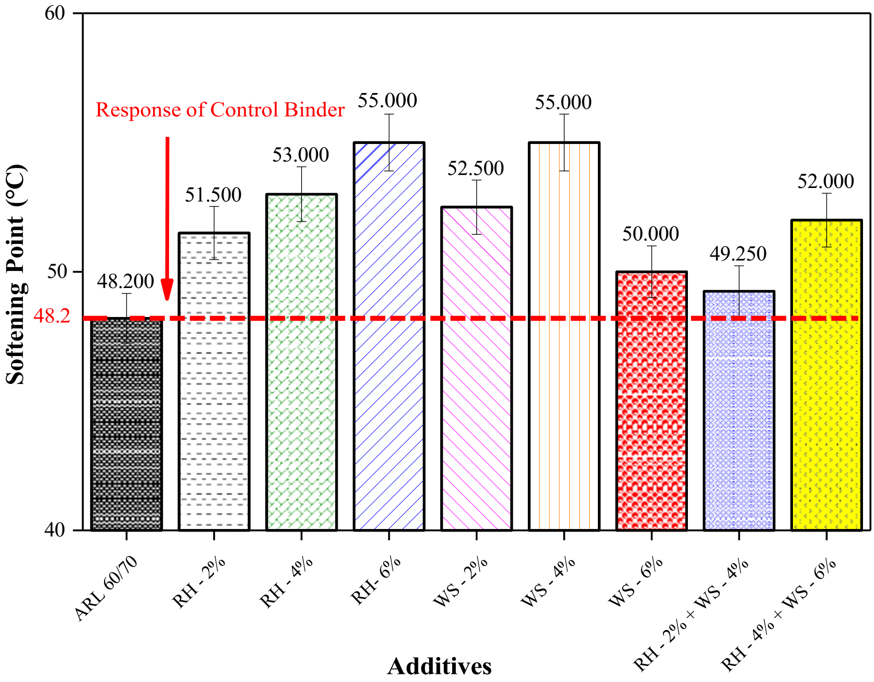

Figure 6: Effect of agricultural waste on Softening Point values

In summary, adding rice husk and wheat straw significantly affected the softening point of bitumen. The results showed that the softening point of bitumen was increased with the addition of these agricultural wastes. The rise in softening point values indicated that the modified bitumen had become harder and more rigid and suitable for places with high temperatures.

Alternatively, neat bitumen possesses a lower softening point, as shown in neat bitumen in Figure 6. A low softening point is desirable for such areas as it makes the bitumen more flexible and less prone to cracking, especially under low temperatures. In conclusion, adding rice husk and wheat straw helps increase the softening point of bitumen, as shown by the modified bitumen with higher softening point values, which provides a harder and stiffer material, making it more suitable for higher temperature zones. In contrast, neat bitumen with a lower softening point is preferred for colder climates.

4.3 Ductility Test Results

The ductility of bitumen compared to neat bitumen is illustrated in Figure 7 below. These figures and table classify how the inclusion of several agricultural wastes — specifically rice husk and wheat straw — at several percentages influence the ductility of bitumen.

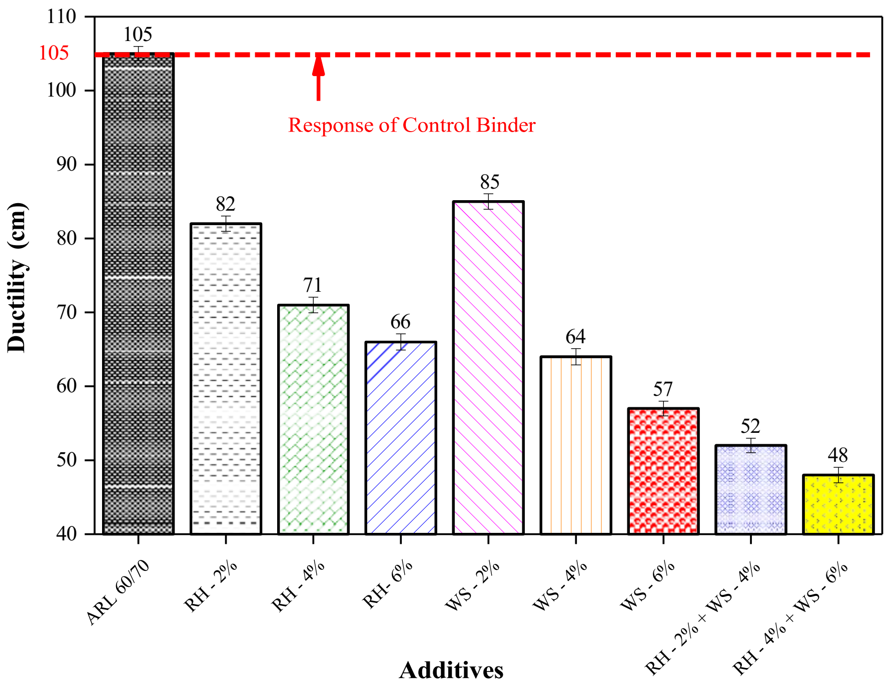

Figure 7: Effect of agricultural waste on Ductility values

It is very clear from the graph below that as you increase the percentage of rice husk or wheat straw, the ductility of the bitumen decreases, depicting a clear trend. It indicates that the modified bitumen reduced the ability to deform without breaking, something quite the opposite of the neat bitumen. The results indicate that the ductility of neat bitumen is significantly higher, measuring 105 centimeters, compared to the modified bitumen, which has a much lower value of 48 centimeters. It implies that the ability of the bitumen to stretch without breaking decreases when modified with agricultural waste. Based on these findings, it is recommended to use neat bitumen in high-temperature zones where its superior ductility is advantageous, while modified bitumen can be preferred in low-temperature zones due to its specific properties.

5 Conclusions

1. A combination of rice husk and wheat straw is mixed in the bitumen, and the penetration value approaches that of the neat bitumen. It suggests that adding both waste materials mitigates the extent of the decrease in penetration value observed when using individual waste percentages.
2. The modified bitumen becomes harder and more rigid by incorporating higher percentages of agricultural waste.
3. As the percentage of agricultural waste increases, the ductility of the modified bitumen decreases.
4. Optimal performance is achieved when the mixture of Rice Husk and Wheat Straw is added at a ratio of 4% and 6% in the bitumen.

Further research should focus on fine-tuning the mixture ratios to achieve the optimal balance of properties that meet the requirements of different temperature zones and road conditions.

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