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Research Article

Evaluating the Rheological Behavior of Bone-Glue Modified Asphalt

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Abstract – Worldwide, asphalt is one of the most widely utilized materials in pavement constructions. The loading and temperature conditions have a significant impact on the asphalt behavior. Various additives have been used over time to enhance asphalt's performance at both high and low temperatures. As the weather in Pakistan is hot for the majority of the year, flexible pavements benefit from the use of asphalt binders that are resistant to the effects of high temperatures. Researchers have attempted to enhance the asphalt mixture's high-temperature performance by adding acids, polymers, fibers, and extenders. In this study, bone glue (BG), a biomaterial produced from animal waste, was added to a base binder in concentrations of 2%, 4%, and 6% by weight. The BG is made in an environmentally responsible manner. It is a natural material that saves money and does not harm the environment. It also results in a long-lasting asphalt composite. Testing methods, such as consistency and rheology analysis, were used to determine how much of an impact bone glue had on asphalt binder. The results demonstrated that the asphalt binder's high-temperature performance was significantly enhanced by the incorporation of bone glue. Rheological testing revealed that a binder concentration of 6% BG by weight produced the best results.

Keywords – Asphalt, Bone Glue, Rheology, Dynamic Shear Rheometer, Biomaterial

I. INTRODUCTION

Transportation infrastructure in Pakistan is largely made up of flexible pavements. Flexible pavements are often built with asphalt binder as the main building component. Due to its viscoelastic nature, asphalt binder reacts strongly to changes in temperature and vehicle loads. In Pakistan, rutting is a typical kind of failure due to the intense summer heat. In addition, asphalt is more prone to rutting since the traffic loading from slow-moving heavy vehicles increases its viscosity [1], [2].

Pavement experts are continually on the search for novel and useful asphalt modifiers to improve the longevity and durability of flexible pavements and their performance in both hot and cold climates. The performance of flexible pavements can be enhanced by modifying the aggregate gradation and/or the origin [3]. Polymers including polyethylene (PE), styrene–ethylene/butylene–styrene (SEBS), and polypropylene (PP), [4], [5], crumb rubber [6], and pricey nanomaterials [7], [8] are all modifiers that might be used to improve the asphalt binder's characteristics.

Especially in developed countries, polymer-modified asphalt has been widely adopted. Contractors and scientists are concerned about the high cost of polymer and the extensive energy requirements. When polymers are added to a bitumen or asphalt mixture, the temperature must be between 65°C and 190°C for an extended length of time (60–200 minutes) before a homogenous blend is achieved. Another major issue with modified asphalt is how long it will last after it has been installed. Polymer enhancement of asphalt is pricey in addition to the aforementioned issues. As a result, it is primarily used in developed nations.

In the past, the rheological qualities of pure binder have been enhanced by using bone glue [9]. The process of combining BG with an asphalt binder has been established [10]. BG is a biomaterial made from collagen protein, which constitutes approximately 20% - 35% of an animal's total body protein and is primarily found in the skeleton [11].

BG's primary input is dead animals. It's widely available in developing nations like Pakistan, but because of its limited use, there are stringent limits on how it can be prepared. The furniture manufacturing business is the primary user of this material. If BG can be successfully used as an asphalt binder modifier, it could provide a low-cost alternative to more conventional modifiers. According to Pakistani market bids, the price ranges from $0.8 to $1.9 per kilogramme, with additional discounts available for large orders. As of a 2013 assessment, just 20 facilities in Pakistan were producing BG to meet domestic demand for wood glue [10]. The production of BG is extremely low as compared to that of synthetic glue. The advantages of synthetic glue have led to a decrease in BG's local use.

Pavement professionals in industrialised nations are increasingly turning to performance grading (PG) rather than the traditional method of penetration grading for characterising the performance of binders in a given climate.

The goals of this research are to (1) evaluate whether or not BG addition to asphalt binder can improve the material's performance, and (2) investigate the effect of BG on asphalt binder rheology. By studying the effect of bone glue on asphalt binder, this research aims to provide a low-cost alternative to conventional asphalt modifiers, which can improve the endurance and lifespan of flexible pavements in Pakistan.

II. Materials and Method

A. *Materials*

Bitumen with a penetration grade of 60/70 was used, since that is the standard in Pakistan for constructing flexible pavements.

The bone glue (BG) was acquired from a vendor. BG is a residual material from the agricultural and livestock industries [9]; animal by-products are a primary source for the production of bone glue.

B. *Mixing Proportion*

The BG mixing method created by Rizvi et al. [10] was used, for this research. Before adding it to the asphalt binder, BG was mixed with water to ensure even distribution. For 60 minutes at a shear mixer speed of 1500 rpm and a temperature of 180 degrees Celsius, BG was combined with 2%, 4%, and 6% concentrations of a base binder. After the specimens were prepared, they underwent a set of tests meant to differentiate between the behaviour of base binders and BG-modified binders.

Table 1. Test dose of BG

Sr. No	Dosage
1	Base Binder + 2% BG
2	Base Binder + 4% BG
3	Base Binder + 6% BG

C. *Experimental Method*

The penetration and softening point tests were carried out in accordance with ASTM D1586, D113, and D36, respectively, in order to evaluate how the addition of BG affected the base binder.

The rheological properties of asphalt binder were evaluated using an Anton Paar dynamic shear rheometer (DSR) at both high and intermediate temperatures. Performance grading, frequency sweep, and MSCR testing were carried out in compliance with AASHTO T 315 [12]. Samples tested at temperatures above 46°C were run on a DSR plate with a 25 mm geometry, while those tested at temperatures below 46°C were run on a DSR plate with an 8 mm geometry.

According to the super pave criteria, the limiting strains for base and BG-modified binder in the frequency sweep test were 10% and 0.45%, respectively. For geometries of 8 mm and 25 mm, the distance between the plates was maintained at 2 mm and 1 mm, respectively. This experiment was run at a range of frequencies (0.1–10 rad/s) and temperatures (22–34°C, 46–58°C, 70–82°C). The rheological characteristics were analysed by measuring the phase angle (δ), rutting factor (G∗/sinδ), and complex shear modulus (G∗).

The multiple stress creep recovery test conducted at temperatures of 58, and 64°C, because the max PG of our BG-modified asphalt binder is 64. The stress levels ranged from 0.025 to 25.6 kPa over the course of ten cycles, with the plate geometry being 25 mm in thickness. The multiple stress creep recovery (MSCR) test included a one-second period of steady creep stress, then letting it relax for 9 seconds. Strain percentages were determined to be recoverable or nonrecoverable after 10 cycles [13].

III. RESULTS AND DISCUSSION

A. *Conventional Testing*

Conventional tests were used to look into how the BG additive influenced the base asphalt. To find out if the modified asphlat was softer or harder, researchers performed penetration and softening point tests. The stiffness of asphalt binder at room temperature is reflected in the penetration value. The stiffer the binder, the lower the penetration value. Figure 1 shows that a higher BG content in bitumen results in a stiffer binder due to a lower penetration value. The penetration values were found to decrease by 8%, 14%, and 21% depending on the dosage of BG (2%, 4%, and 6%). Bitumen's deformation characteristics at high temperatures are reflected by the softening point test. The increase in softening point was 3 degrees Celsius for 2% BG, 6 degrees for 4% BG, and 10 degrees for 6% BG. Bitumen's stiffness comes from its high surface energy and the presence of intermolecular forces; these factors may explain why bone glue has a higher softening point and lower penetration [14].

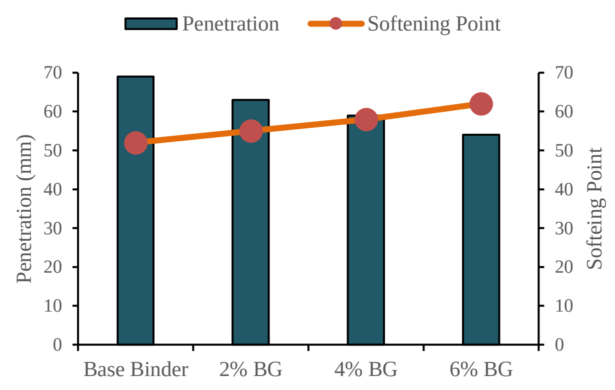

Fig 1 Penetration and Softening point values of Base binder and modified binders

B. Analysis of the Rheology of BG- Modified Asphalt Binder.

The rheological properties of asphalt binder were studied using a dynamic shear rheometer at varying temperatures and frequencies. Master curves for G∗, G∗/sin δ, and δ, were generated at 58°C and are shown in Figures 2-4. Complex shear modulus (G∗ values are shown in Figure 2 for a range of frequencies. At high temperatures, it is clear that the addition of BG increases the asphalt binder's stiffness, reaching a maximum value at 6 percent. Adding BG also makes the asphalt binder rigid, which provides greater protection against permanent deformation.

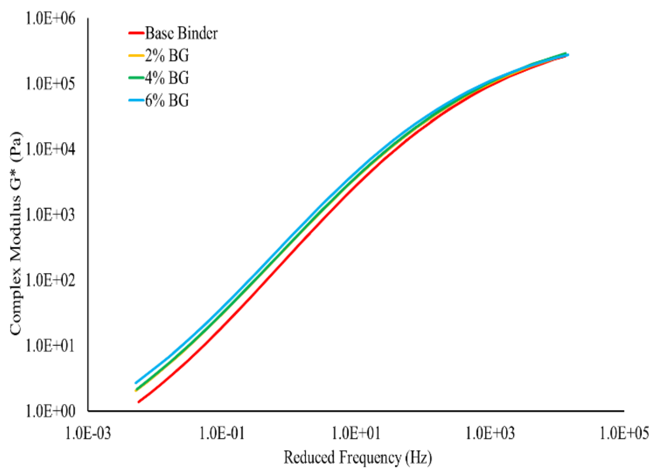

Fig 2 Master curve for complex modulus (G∗) at 58°C.

Bitumen is characterised as a viscoelastic material due to its elasticity at low temperatures and its viscosity at high temperatures. The elastic or viscous behaviour of bitumen can be characterised by looking at the phase angle (δ). In Figure 3, we see that as loading frequency drops or temperature rises, phase angle values gradually increase. Adding

BG caused a reduction in phase angle across the board, with the greatest effect seen at 6 percent BG content, where the phase angle dropped by 15 percent at 10 Hz. The phase angle has decreased, revealing that bitumen's elastic properties have improved [15]. The results show that BG has enhanced the asphalt binder's elastic properties, which decreases the probability that the material will undergo permanent deformation when subjected to higher temperatures.

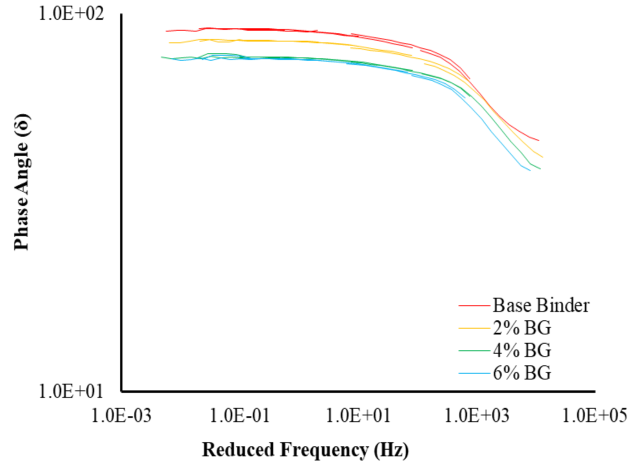

Fig 3 Master curve for phase angle (δ) at 58°C.

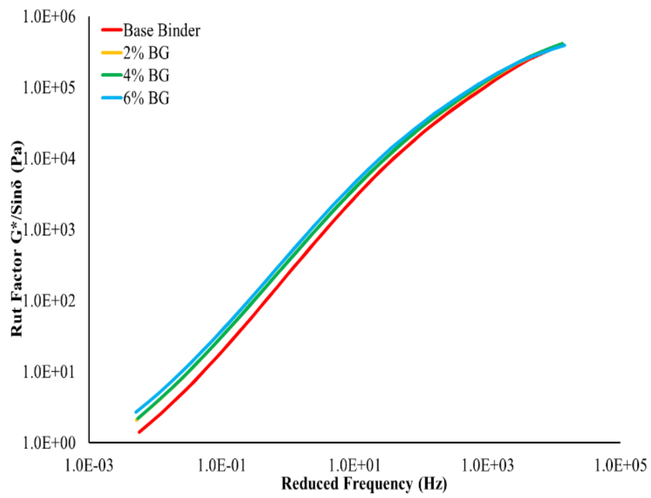

Fig 4 Master curve for Rut factor (G∗/sinδ) at 58°C.

Rutting is the most significant problem associated with asphalt roadways. Rutting happens when the pavement is compressed in the wheel path as a result of high temperatures and heavy traffic. The rutting factor, denoted by G∗/sin δ, is a useful metric for analysing pavement performance in terms of its resistance to permanent deformation under severe heat conditions [15]. As can be seen in Figure 4, the addition of BG to asphalt binder increases its resistance against permanent deformation and its elastic behaviour at high temperatures, making it more resistant to rutting.

Mix rutting causes flexible pavement to fail too soon in high temperatures and is the biggest issue facing Pakistan's pavement industry. Because of this, PG-64 is suggested for use in countries with particularly hot climates [16]. Figure 5 displays the results of an analysis of the effect of BG on the asphalt binder PG. With the addition of 2% BG to the asphalt binder, the failure temperature rises from 62.4 degrees Celsius to 64.1 degrees Celsius. Additionally, the PG-58 is improved to PG-64. Adding 6% BG to the asphalt binder increased the failure temperature from 62.1 to 67.9 degrees Celsius. This resulted in the grade being increased to PG-64, which indicates that a 6 percent BG-modified asphalt binder is capable of meeting the performance grade requirement in the majority of Pakistan's climate zones.

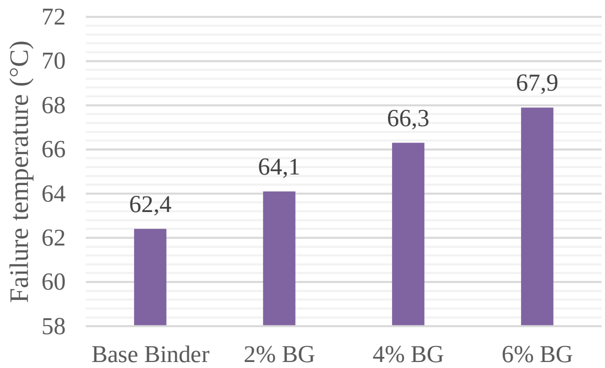

Figure 5 failure temperature of BG modified asphlat binder.

C. Creep analysis.

Evaluation of the creep recovery performance of BG binders was performed using the multiple stress creep recovery (MSCR) test at temperatures of 58°C and 64°C. Since PG-64 is the desired performance level, tests were run at 64°C to see how varying degrees of stress impacted asphalt binder Jnr values. Figure 6 shows that as stress is increased, the Jnr value rises linearly to a maximum at 25.6 kPa.The Jnr value is highest for base asphalt binders and lowest for those modified with BG at 6 percent by weight. This is due to the fact that BG enhances the stiffness of the asphalt binder, which enables it to recover more quickly when the stress is released. As a result, asphalt binders that have a lower Jnr value have a stronger tendency to return to their initial position, and vice versa. The reduction in Jnr that occurred as a result of the addition of 6 percent

BG was 32.42 percent. The stiffness of the asphalt binder is due to intermolecular forces present in BG, which is the root cause of the declining Jnr value [17].

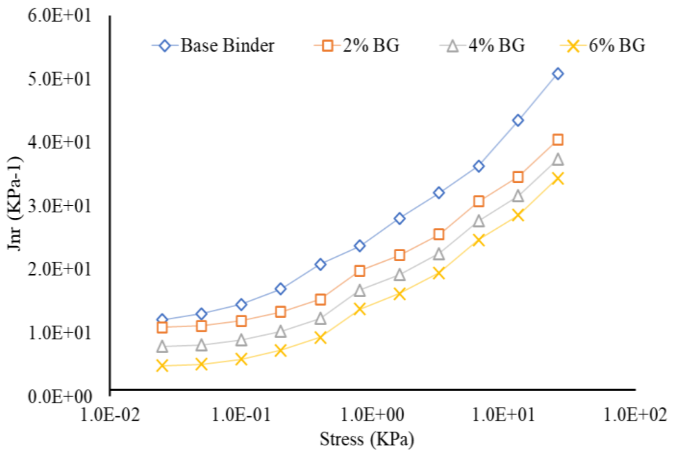

Fig 6 Asphalt binder Jnr values at 64 degrees Celsius.

IV. CONCLUSION

The following conclusions may be deduced from the results of this research:

- The asphalt binder has become stiffer with the addition of bone glue, as evidenced by a decline in the binder's penetration values and an increase in its softening point.
- Increases in complex shear modulus and rut factor, as well as decreases in phase angle and Jnr, show that bone glue improves the elastic behaviour of the binder.
- High-temperature performance grade (PG) is increased from PG-58 to PG-64 when 6 percent bone glue is added to the asphalt binder, making it suitable for use in most of the country's climate zones.
- Based on the results of the experiments, it was determined that adding 6 percent bone glue to the asphalt binder is the optimal dosage for improving asphalt qualities.

Overall, the study demonstrates that bone glue has great promise as a viable modifier for improving asphalt binder performance, particularly with regards to stiffness, rutting resistance, and high-temperature performance. Bone glue modified asphalt binder has shown promise, but more research is needed to determine its long-term durability.

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