Influence of Tire Crumb Rubber on Properties of Asphalt Binders

G J Qasim¹, S A Tayh¹ and R A Yousif¹
¹Highway and Transportation Engineering Department, College of Engineering, Mustansiriya University, Baghdad, Iraq
E-mail: sady.tayh75@uomustansiriyah.edu.iq (S A Tayh)

Abstract. For many years, the asphalt binder has been used as the elemental material for pavement engineering. The increase in axle loads, heavy traffic, severe climate conditions and construction failures has led many researchers to seek some methods to enhance the bitumen properties. There is a wide range of applications of modifiers for bitumen in road construction. Although various kinds of modifiers have been used widely in reinforcing asphalt concrete, crumb rubber has attracted the most attention due to its high and desirable characteristics. It is realized that the well-distributed modifier can create a strong network in the internal structure of the composite, resulting in asphalt mastic that is more coherent. In the present paper, a laboratory investigation of the physical and rheological properties of various grades of asphalt binder (60-70 penetration grade, 80-100 penetration grade and PG-76 grade) modified with tire crumb rubber. The results showed improvement in physical properties of the modified asphalt binders in terms of decreasing in penetration, increasing in softening point and viscosity values. The modified bitumens exhibited enhanced rheological performance and could raise the grade of bitumen relying on the base asphalt type.

1. Introduction
Due to many reasons such as the heavy traffic movement, rise in axle loads, critical changes climate, the fast rise in asphalt materials costs, and pavement construction problems, numerous researchers have tried to seek some materials and methods to boost the asphalt binder properties by coming out with better viscosity and lower priced binders suitable for asphalt pavement construction [1,2].

Regarding the growth of use of bitumen all over the globe, some trials were directed to advance the characteristics of it. These trials have managed to discover more proper materials involved in the construction of asphalt pavement [3,4].

Rubber reproduced from waste tires was utilized for an extensive diversity of industrial purposes. Diverse approaches were accustomed to study the mix of crumb rubber modifier in road paving materials [5].

Many researchers have attempted modify the traditional binders utilizing waste crumb rubber. Their results have revealed that crumb rubber could enhance the physical properties of the base bitumen by increasing its consistency at high service temperatures and reducing the creep stiffness at low service temperature [6]; and enhance the rheological properties and elastic modulus at high service temperature [1,7,8]. Generally, the use of reclaimed rubber in bitumen boosts the overall mechanical properties of asphalt mixtures [9].
2. Materials and Methods

2.1 The Asphalt Binders
For the rationale of exploring the influence of crumb rubber on different asphalt binder grades, three grades of asphalt were used as base asphalt binders (80-100 and 60-70 penetration grade asphalts as well as PG-76 performance grade asphalt). The laboratory testing was done to assess the bitumen binders’ fundamental properties as can be seen in Table 1.

Table 1. The Physical Properties of Asphalt Cement

| Binder properties                              | Specification | 80-100 | PG-76 | 60-70 |
|------------------------------------------------|---------------|--------|-------|-------|
| Penetration (25 °C) (0.1mm)                    | ASTM D5       | 84     | 33.5  | 63.5  |
| Softening point °C                             | ASTM D36      | 46.5   | 73.5  | 49    |
| Viscosity at 135°C (cpoise)                    | ASTM D4402    | 297.45 | 1541.8| 382.3 |
| Ductility (25°C, 5cm/min)                      | ASTM D113     | >100   | >100  | >100  |
| Specific gravity at 25°C (g/cm³)               | ASTM D70      | 1.036  | 1.03  | 1.04  |

2.2 Tire Crumb Rubber
The reclaimed rubber utilized in this research is premium and super-fine grade (40 meshes) tire crumb rubber manufactured from the selected crushed and discarded tire material. This material is compliance with the Restriction of Hazardous Substances (ROHS) requirement. As a result of the unique process and stringent quality control, T-MESH 40 offers a high passing rate and free of foreign contaminants in its properties. Table 2 and 3 present the physical properties and chemical composition of the used reclaimed Rubber (T-MESH 40) [10].

Table 2. Chemical composition for the reclaimed tire rubber

| Acetone Extract % | JIS K 6350 | 10±5 |
|-------------------|------------|------|
| Ash Content %     | TGA        | 5±3  |
| Carbon Black %    | TGA        | 32±5 |
| Rubber Hydrocarbon % | TGA      | 52±8 |

Table 3: Physical composition of tire crumb rubber

| Passing %          | ASTM D 5644 | > 90 |
|--------------------|--------------|------|
| Heat Loss %        | ASTM D 1509  | < 1  |
| Metal Content %    | ASTM D 5603  | ≤ 0.1|
| Fiber Content %    | ASTM D 5603  | ≤ 0.3|

All specimens were made utilizing the same control asphalt types and the proportions of total binder weight. The asphalt rubber binders was made by adding crumb rubber modifier to the base asphalt binder by the rate of 1, 3, 5, 7 and 9 % by the weight of the base binder, and blending them using a high rate of shear mixture (1000 rpm) at 177°C with duration of 30min. The blending process was sustained until the steady state was met.

3. Results and Discussion

3.1 The Conventional tests
The traditional tests, like softening point, penetration, and viscosity tests were ran on neat and modified bituminous binders as follows.

3.1.1 Penetration Test. Figure 1 shows the percentage of reduction in penetration values for neat and modified asphalt binders. From this figure, it can be noticed that with the increase in the percentage of
modifier, the value of penetration decreases. The effect of the crumb rubber modifier on softer asphalt binders such as 80/100 and 60/70 was significant, while the penetration value of samples of modified high-quality binder (PG76) did not change significantly. This is might be due to the existence of the polymer modifier in PG76 binder that may limit the effect of the rubber modifier on the base asphalt.

Figure 1. The influence of crumb rubber proportion on penetration of bitumen

3.1.2 The Softening Point Tests. As opposed to the penetration measurements, with the rising proportion of the crumb rubber, the softening point value increased. The percent of rise in softening point values are shown in Figure 2. It is clear also, the rise in the softening point was values were relational to the modifier proportion, although, the effect of the crumb rubber modifier on softer asphalt binders such as 80/100 and 60/70 in terms of softening point rising was significant, while the effect was less on samples of modified high-quality binder (PG76).

Figure 2. The influence of crumb rubber content on softening point for bitumen

3.1.3 Viscosity Tests.
Figure 3 shows the viscosity values of control and modified bitumens. The viscosity values of the rubber modified bitumens were higher than those of the control bitumens. The more rubber modifier is inserted into the control bitumen, the greater viscosity values are gained. All viscosity data of modified asphalt binders were below the maximum allowable value (3 Pa.s), and so do pass the specification standard of
Superpave™. Extreme viscosity is unhelpful for the workability during transportation and mixing of the bitumen.

![Figure 3](image)

**Figure 3.** The Influence of crumb rubber proportion on viscosity of bitumen

Based on the previous results, the addition of tire crumb rubber to the asphalt binders enhances the physical properties of the modified bitumen binders as indicated by the reduction in penetration value and an increase in softening point, and an increase in the viscosity values, thus enhancing modified binder stiffness and increase its ability to resist rutting deformation. However, this may negatively affect the fatigue performance of the modified asphalt binders due to the extreme increase in stiffness.

3.2 The Rheological Performance

The rheological performance of the crumb rubber modified bitumens were determined utilizing a dynamic shear rheometer (DSR, HAAKE, Rheo Stress RS1, Phoenix) through a wide-ranging temperatures to characterize viscous and elastic behaviours of unaged modified binders. Two 25mm diameter parallel steel plates with a 1mm space were used to perform the DSR measurements. A constant sinusoidal stress of 0.12 kPa was employed, and the strain was set as low as possible so as to all the experiments to be performed inside the linear range of the viscoelasticity. Various parameters were determined during DSR tests, including complex modulus ($G^*$) and phase angle ($\delta$). Furthermore, the rutting parameter ($G^*/\sin\delta$) was used to primarily measure the resistance for rutting and stiffness of the asphalt mastics.

3.2.1 Temperature Sweep Test at High Temperature. The fundamental rheological performance of the modified asphalt binder, tire crumb rubber (T-MESH 40), were determined by temperature sweep test for the unaged binders using dynamic shear rheometers (DSR). A DSR Oscillation Temperature sweep test was performed at intermediate and high temperatures that ranged from 40 to 82°C with a 6-degree step to determine the change in binder performance as a function of temperature change at a 10 rad/s frequency. It is advised a minimum value of 1.0 kPa for $G^*/\sin\delta$ to guarantee that binder is resistant enough to permanent deformation at high service temperatures. The minimum limit for $G^*/\sin \delta$ is 1000 Pa for unaged bitumen. Figures 4 - 6 present the relation between the rutting factor and temperature during temperature sweep test showing the failure temperatures for the three types of modified binders.

The modified asphalt binders have higher values of rutting factor than the control binders. Reducing the rutting susceptibility and improving the permanent deformation resistance at high temperature is the modified binder behavior according to the specification. Can note from table 4, the failure temperatures of the rubber modified asphalt binders values are higher than control asphalt binder is. As a result, the high-temperature grade (PG) for the base binders has been increased.

The addition of different percent of crumb rubber to the asphalt makes the control asphalt binder stiffer than before. When loading is applied, the asphalt binder can reflect more energy and indicate that the modified asphalt binders have more resistant ability to rutting and fatigue cracking under high and
intermediate temperatures, this can be detected High complex shear modulus and rutting factor of these modified asphalt binders.

Base binder PG76 was the highest in terms of rutting resistance and stiffness followed by 60/70 and 80/100 binders respectively. Therefore, the neat binder type of a great impact on G*/sin δ of all bitumens in this research.

Figure 4. Temperature sweep test for 80-100 asphalt binder modified with crumb rubber

Figure 5. Temperature sweep test for 60-70 asphalt binder modified with crumb rubber

Figure 6. Temperature sweep test for PG76 asphalt binder modified with crumb rubber
Table 4. Failure temperature of the modified binders

| Binder Type | 0   | 1   | 3   | 5   | 7   | 9   |
|-------------|-----|-----|-----|-----|-----|-----|
| 80-100      | 62.8| 65.8| 69  | 71.6| 73  | 74.1|
| 60-70       | 69.5| 67.8| 69.4| 71.5| 73  | 76  |
| PG76        | 76.5| 76.8| 77.6| 79.5| 81  | 81.7|

It could be obvious that the neat binders are classified as PG58, PG64, and PG76, respectively. Coming back to the maximum failure percent of crumb rubber additive to each control asphalt type according to viscosity test results in Table 7, the addition of 1% to 9% crumb rubber 80-100 and 60-70 asphalt binders, respectively, had enhanced the PG grading two steps for 80-100 binder from PG58 to PG70 and enhanced PG grading one step from PG64 to PG70.

4. Conclusions

In this research, the influence of crumb rubber on three asphalt binder types was studied. There are several conclusions derived from the results:

- The modifier is well dispersed in the asphalt, due to no blocks or agglomerates can be seen after the blending process.
- The addition of crumb rubber to the neat binders, enhances the fundamental properties of the base asphalt binders as specified by the decrease in penetration value and an increase in softening point temperatures.
- The use of crumb rubber in asphalt binder could considerably increase the viscosity of the asphalt. This could be helpful to improve the high-temperature performance of bitumen.
- The excellence of the neat asphalt mastic could be a key factor, whereas higher consistency base mastic demonstrated little improvement (PG76). At the same time, the lower consistency binder types demonstrated considerable improvement in the properties (80-100 and 60-70 binders).
- The DSR tests demonstrated that crumb rubber bituminous mastics have better rutting parameters (G*sinδ) related with the base asphalt mastics.
- As a result of high crude oil costs and also considering the high price of the polymer as a modifier, reclaimed tire rubber might be utilized as a successfully alternate to boost the rheological behavior of the asphalt binder.

References

[1] Youssif R A, Kareem Q S and Ellk D S 2012 Effect of additives types and contents on permanent deformation J. Eng. Sust. Dev. 16 258-68.
[2] Muniandy R, Jafariahagari H, Yunus R, and Hassim S 2008 Determination of rheological properties of bio mastic asphalt Amer. J. Eng. Appl. Sci. 1 204-9.
[3] Airey G D 2004 Fundamental binder and practical mixture evaluation of polymer modified bituminous materials Int. J. Pav. Eng. 5 137-51.
[4] Kim Y R 2009 Modelling of asphalt concrete 1st ed. North Carolina: McGraw-Hill Professional
[5] Bahia H U and Davies R 1994 Effect of crumb rubber modifiers (CRM) on performance related properties of asphalt binders Asph. Pav. Technol. 63 414-38
[6] Wang H, You Z, Mills-Beals J and Hao P 2012 Laboratory evaluation on high temperature viscosity and low temperature stiffness of asphalt binder with high percent scrap tire rubber Cons. Build. Mat. 26 583-90
[7] Kumar P, Mehdinatta H C and Singh K L 2009 Rheological properties of crumb rubber modified bitumen-A lab study J. Sci. Ind. Res. 68 812-6
[8] Mashaan N S, Ali A H, Karim M R and Abdelaziz M 2011 Effect of crumb rubber on centration on the physical and rheological properties of rubberized bitumen binders Int. j. phys. Sci. 6 684-90.
[9] Sienkiewicz M, Borzedowska-Labuda K, Zalewski S and Janik H 2017 The effect of tyre rubber grinding method on the rubber-asphalt binder properties Const. Build. Mat. 154 144-54

[10] Tayh S A and Yousif R A 2018 Effect of blending speed and blade level on the properties of reclaimed rubber modified bitumen ARPN J. Eng. Appl. Sci. 13 836-92.