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Use of local crumb rubber as modifier, to improve the rutting resistance of bitumen

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ABSTRACT

Bitumen is a critical component in asphaltic pavements and is often the cause of many road failures. The commercial modifiers that are being used to enhance the properties of bitumen are quite expensive; therefore, this article is dedicated to explore the potential of local crumb rubber as bitumen modifier. Two grades of bitumen pen grade (60/70 and 80/100) were modified with local crumb rubber. Rheological properties of modified and unmodified bitumen were evaluated using Dynamic Shear Rheometer. The results indicated an increase in the rutting resistance of bitumen. This indicates that Local crumb rubber can be used to enhance the properties of bitumen.

KEYWORDS

pavement materials, local crumb rubber, polymeric modification, rheology, rutting resistance

1. INTRODUCTION

Bitumen is a viscoelastic material and its properties change with change in temperature and also with rate of loading, Brown [1]. It behaves like a viscous liquid at high temperature or low rates of loading and is prone to rutting failure; whereas at low temperature or high rates of loading it becomes brittle and is prone to cracking Subhy [2]. Rutting is one of the most frequent occurring defect of asphaltic pavements Adorjányi et al. [3]. The bitumen resistance to rutting are analyzed using Strategic Highway Research Program (SHRP) rutting parameter $G^*/\sin(\delta)$ with G^* and δ being complex modulus and phase angle of the bitumen respectively Cominsky et al. [4]. Various polymer based additives are used to improve the rheological properties of bitumen for instance resistance to rutting. One of these polymer additives is the Crumb Rubber (CR), which is produced by shredding End of Life Tires (ELTs) [5, 6].

In order to achieve bitumen modification, bitumen and CR are interacted at elevated temperature. The reaction that takes place between bitumen and CR results in swelling of CR particles this is achieved by absorption of lighter fractions of bitumen into the CR. This reaction depends upon factors like time and temperature at which the two materials interact. The modification of bitumen is primarily achieved due to absorption of lighter fraction by CR particles Shen et al. [7], Abdelrahman et al. [8]. According to various studies if the temperature or time of reaction is increased beyond a certain limit, it will result in depolymerisation of the CR particles, which will result in degradation of rheological properties of modified bitumen Presti et al. [9], Abdelrahman et al. [8]. According to Mashan et al. [10] main factor that affects the performance of modified bitumen is the quantity of CR, no significant difference in properties was observed by Mashan et al. between two blending times of 30 and 60 min. Various researches have reported that bitumen modified with crumb

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rubber has improved rutting resistance i.e., higher G^* value and improved elastic properties i.e., lower δ value Shen et al. [11].

The researches that have previously been carried out have used CR produced solely from vehicle tires and have not used the Local Crumb Rubber (LCR). LCR is a waste product that is produced during miscellaneous manufacturing processes in particular the *use of scrap rubber products* (conveyor belts, ELTs etc.) as shoe soles. In Pakistan in the areas that experience hot climate, the pavement temperature can rise up to 73 °C, Mirza et al. [12], thus there is a need for a binder that can offer sufficient resistance to deformation at high temperatures at the lowest cost. Since LCR is a waste material this research seeks to evaluate the performance of LCR as a bitumen modifying agent to increase the service life of asphalt concrete road pavements. Moreover, this research will help in reutilizing the solid waste produced in the form of LCR. This research aims to investigate the potential of LCR for use in construction industry as a bitumen modifier.

2. MATERIAL AND METHODS

Waste rubber from ELTs, conveyor belts etc., is used in local shoe industry as shoe soles. During this manufacturing process, the rubber is grinded, cut and smoothened using grinding wheels. This process produces rubber waste that is locally known as rubber powder (Fig. 1) and for this study will be referred to as LCR.

LCR passing sieve no 30 was used as modifier having the following gradation (Table 1).

To assess the constituents of the LCR, Thermo-Gravimetric Analysis (TGA) was performed at Centralized Resource Laboratory (CRL) at university of Peshawar. TGA is a powerful tool to analyze and identify materials. In order to perform TGA a mass of sample weighting around 10–20 mg is placed in a pan that is attached to a microbalance. The mass of sample is heated in the furnace of TGA apparatus from an initial temperature to the desired temperature in the presence of Nitrogen as a purge gas that is injected within the furnace at a predefine rate. This is done to purge the furnace of gases that are created during heating of the sample to avoid thermal oxidative degradation of the sample. Continuous weight loss measurements are taken and TGA curve is generated by plotting percentage weight loss against temperature Chandra et al. [13]. For performing the TGA test, following time - temperature combination were used (Table 2).

The rate of temperature increase was kept at 10 °C min^{-1} throughout the experiment. The LCR constituents were divided into four categories based on material lost at different temperature ranges (Table 3). It includes: extractable, polymer, carbon black and ash Plemons [14]. Figure 2 shows the thermo-gravimetric curve of LCR and Table 4 shows the percentage of each constituent of LCR.

Pen grade 60/70 and 80/100, were used as base bitumen. Varying quantity of LCR (10, 15 and 20%) was used as

Fig. 1. Local Crumb Rubber (LCR) sample

Table 1. LCR gradation

Sieve Number	#30	#50	#100	#200
Percent Passing	100.00	49.10	12.87	4.19

Table 2. Program temperature settings

Temperature	Remarks
30 °C	Initial temperature
30–530 °C	Kept at 530 °C for 10 min
530–850 °C	Kept at 850 °C for 10 min

Table 3. Constituents of LCR at different temperature range

Temperature range	Material
Up to 325 °C	Extractable
325–530 °C	Polymer
530–850 °C	Carbon black
>850 °C	Ash

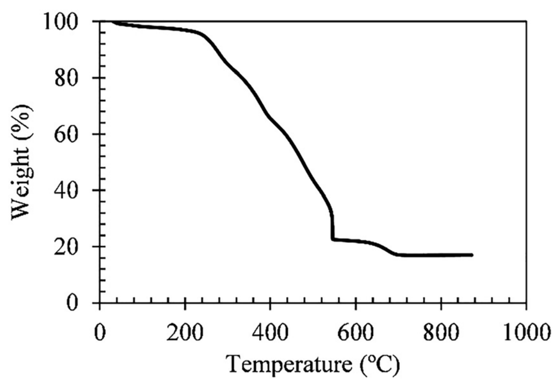

Fig. 2. Thermo-gravimetric curve of LCR

Table 4. LCR constituents

Component	Extractable	Polymer	Carbon Black	Ash
Percentage	19%	44%	20%	17%

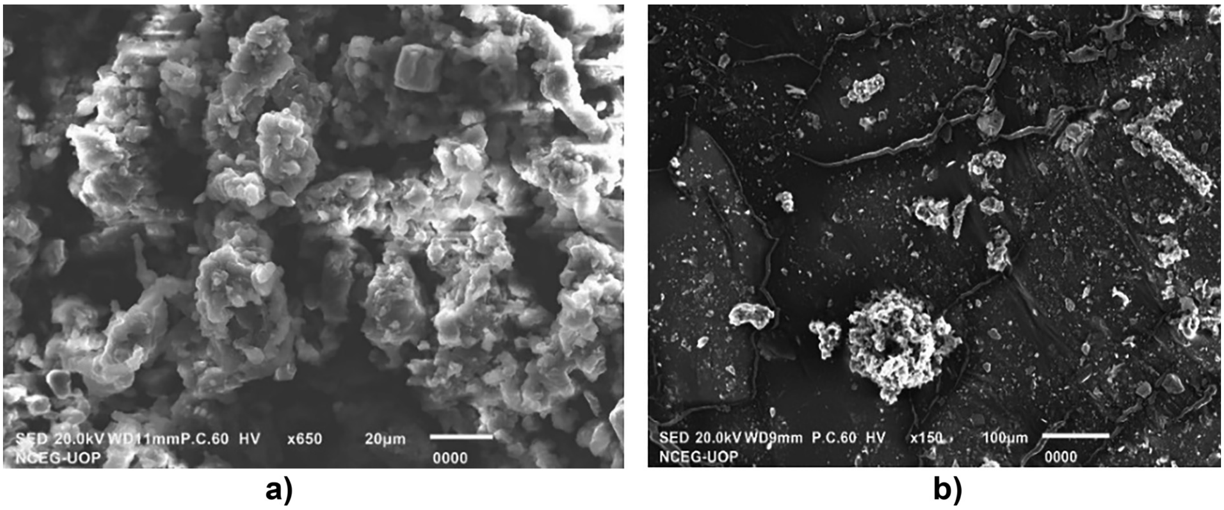

Fig. 3. SEM images of LCR and LCR modified bitumen, LCR at x 650 magnification level (left), LCR dispersed in bitumen phase at x 150 magnification level (right)

additive for bitumen. Mixing was carried out using planetary type laboratory mixer with paddle blades for 30 min at 180 ± 10 °C, keeping the mixer speed constant at 1,400 rpm. To assess the rheological properties of bitumen, Dynamic Shear Rheometer (DSR) was used. In this research DSR plate geometry used was 25 mm parallel plate (pp) with a plate gap of 1 mm. Frequency sweep was run from 0.1 to 100 rad s^{-1} on both LCR modified and unmodified bitumen for the temperature range of 15–75 °C with 10 °C step. To assess the morphology and dispersion of LCR particles in bitumen, Scanning Electron Microscope (SEM) was used. Following images (Fig. 3) were taken using SEM.

It can be observed in Fig. 3a that LCR has a spongy appearance and from Fig. 3b it can be observed that LCR is present as discrete particles in bitumen.

3. RESULTS AND DISCUSSION

3.1. Effect of LCR addition on rheological properties of bitumen

Bitumen is a viscoelastic material; hence its properties depend on the time and temperature when subjected to same loading. Rheological properties, time-temperature dependent characteristic of a material, are therefore necessary to be evaluated. Data obtained from the DSR machine is evaluated using isochronal plots, and rutting parameter.

3.1.1. Isochronal plots. Isochronal plots are plots of phase angle or complex modulus against temperature at a constant frequency. They are useful in indicating the changes in properties of bitumen with the change in temperature Presti [15]. Figures 4 and 5 show the isochronal plot of G^* at a frequency of 10 rad s^{-1}. It can be observed that increasing LCR content increases the value of G^*. This shows that LCR addition results in bitumen having a relatively higher complex modulus. According to Haopeng et al. [16] addition of CR improves the viscoelastic response of the bitumen. Another interesting observation is the difference in the extent of modification between 60/70 and 80/100 bitumen. For instance, at 45 °C, 60/70 bitumen modified with 15% of LCR has a G^* value of 71.6 kPa and it increased by only 5 kPa with a further addition of 5% LCR. However, in case of 80/100 bitumen, G^* increased from 69 to 79 kPa when LCR is increased from 15 to 20%.

Figures 6 and 7 show the values of phase angle δ plotted against temperature at a constant frequency of 10 rad s^{-1}. Increasing the temperature from 15 to 75 °C resulted in an increase in phase angle δ values. Phase angle, δ is basically the tangent inverse of loss and storage modulus of the material. Therefore, it shows the relative proportion of viscous and elastic component of a viscoelastic material. Phase angle δ values lower than 45° shows a material behavior dominant in elastic characteristics while a higher value shows a

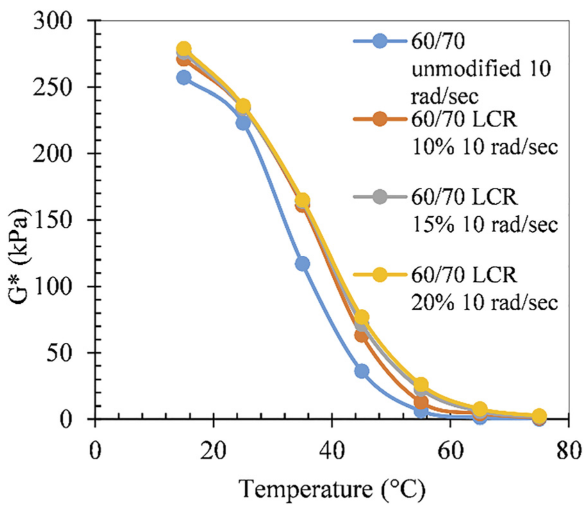

Fig. 4. Isochronal plot of G^* for 60/70 modified with LCR at different concentrations

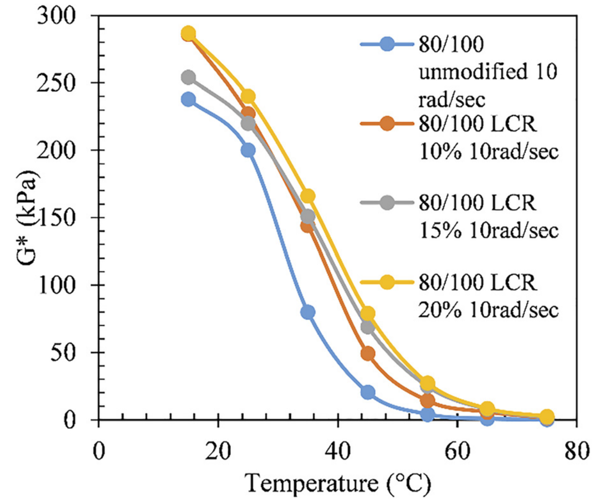

Fig. 5. Isochronal plot of G^* for 80/100 modified with LCR at different concentrations

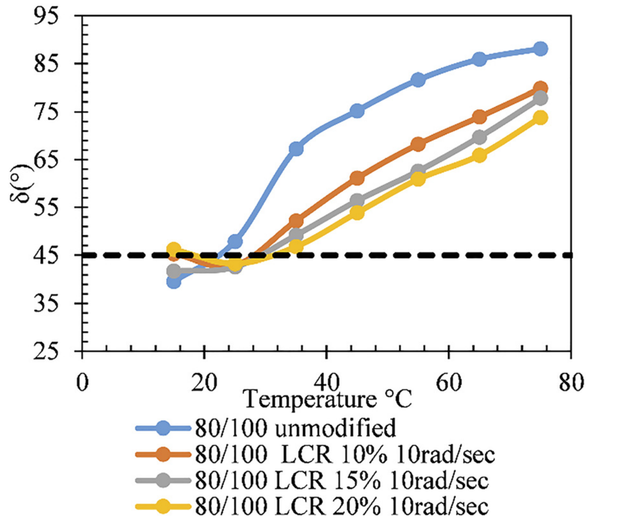

Fig. 7. Isochronal Plot of phase angle for 80/100 modified with LCR at different concentrations

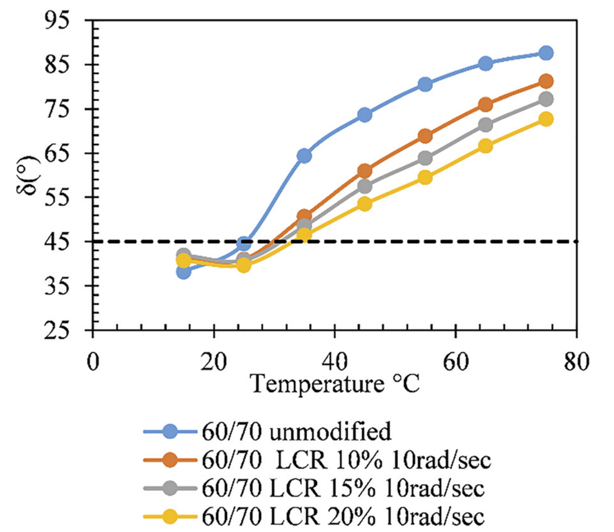

Fig. 6. Isochronal plot of phase angle for 60/70 modified with LCR at different concentrations

dominant viscous behavior. LCR modified bitumen exhibit lower phase angle values at higher temperature when compared to unmodified bitumen. The unmodified bitumen crosses the threshold value of 45° at 26 °C and 23 °C for 60/70 and 80/100 bitumen respectively, with the addition of LCR the graph is pushed further along the horizontal axis with the LCR modified bitumen crossing the 45° line between 30 °C to 34 °C and 29 °C–33 °C for 60/70 and 80/100 bitumen respectively. It can also be observed that the temperature at which the 45° line is crossed continues to increase with the addition of LCR. For 60/70 bitumen the initial increase in the threshold temperature is 15% on addition of LCR in dose of 10% by weight, whereas, on subsequent addition of LCR content in doses of 15 and 20% by weight of base bitumen, the threshold temperature increases by 7 and 6% respectively.

Similarly, for 80/100 bitumen the initial increase in the threshold temperature is 26% on addition of LCR in dose of 10% by weight, whereas on subsequent addition of LCR content in doses of 15 and 20% by weight of base bitumen, the increase in threshold temperature is 7 and 6% respectively. The trajectory of modification for both 60/70 and 80/100 bitumen is the same; however, the threshold temperature values for the softer grade, 80/100 bitumen fall behind 60/70 bitumen. Another interesting observation for LCR modified bitumen was the plunging of the graph on increase in temperature from higher phase angle values at 15 °C to lower phase angle values; this can be attributed to the 1 mm plate gap. According to Mturia et al. [17], for DSR testing of CRM bitumen plate gap adjustment is required to avoid any influence by the CR particles.

3.1.2. Rutting resistance. The rutting parameter, $G^*/\sin(\delta)$ is used to measure the resistance of binder to rutting Mashaan et al. [10]. The value of $G^*/\sin(\delta)$ should be a minimum 1.0 kPa for un-aged bitumen Cominsky et al. [4]. The values of rutting parameter are presented in Fig. 8, it is

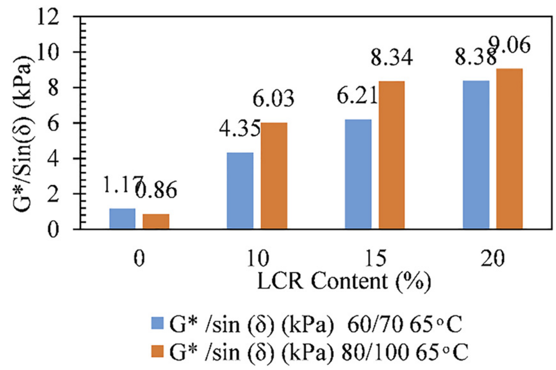

Fig. 8. Improvement in the Rutting resistance of 60/70 and 80/100 bitumen with LCR addition

observed that the value of the rutting parameter increased with the increase in LCR percentage. On addition of 10% of LCR by weight to 60/70 bitumen, the value of rutting parameter increased by 3.7 times; however, on further addition of LCR in doses of 15 and 20% by weight, the rutting parameter value only increased by 1.4 and 1.3 times respectively. For 80/100 bitumen on addition of 10% of LCR by weight the rutting parameter value increased by 7 times , however, on further addition of LCR in doses of 15 and 20% by weight the value of rutting parameter only increased by 1.3 and 1.1 times respectively. This indicates that with the continuous increase in LCR percentage by weight, the bitumen rutting resistance approaches a limiting value from where there is no further increase in the value of rutting parameter.

4. CONCLUSION

From the above discussion it can be concluded that

- Bitumen gets stiffer on addition of LCR, as was evident from the increase in complex modulus values;
- The behavior of bitumen became more elastic with the addition of LCR, as was evident from the decrease in phase angle values;
- The rutting resistance of bitumen was enhanced with the addition of LCR content; this indicates that LCR can help to overcome the problem of rutting;
- 15% of LCR content by weight was observed to be the optimum quantity of LCR as after this no appreciable increase in rutting resistance value was observed. Some overlapping was also observed in G^* isochronal plot of bitumen modified with 15% and 20% LCR content by weight;
- Since LCR is a waste product, before mixing it with bitumen quality control tests like TGA should be carried out to assess the constituents of LCR;
- Further research is needed to establish quality control parameters and to generalize the findings of this research.

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