

Full Length Research Paper

Effect of crumb rubber concentration on the physical and rheological properties of rubberised bitumen binders

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The increase use of crumb rubber in flexible pavements requires the better understanding of its effect on physical and rheological properties of rubberised bitumen binders. The performance properties of rubberised bitumen binder are influenced by the blending conditions and crumb rubber content. The main objective of this research is to investigate the effect of various crumb rubber content on the physical, rheological properties and rutting resistance of rubberised bitumen. Laboratory tests were conducted to evaluate such related properties of bitumen binder with different rubber contents. The tests undertaken comprise the ductility test, elastic recovery test, penetration test and dynamic shear rheometer (DSR) test. The results showed that the addition of crumb rubber has an effect on the physical properties of rubberised bitumen binders, by increasing its elastic recovery and decreasing its penetration and ductility. The rubberised bitumen binder with higher crumb rubber content has an obvious effect on the rheological properties (increase in complex shear modulus G^* , storage modulus G' , loss modulus G'' and decrease in phase angle δ). The results indicated that the rubber content has the potential to resist rutting deformation that occurs in road pavement as result of increased traffic loading.

Key words: Bitumen, crumb rubber, rubberised bitumen, ductility, elastic recovery, penetration, rheology, viscosity, temperature susceptibility, rutting resistance.

INTRODUCTION

In recent years, the researches and applications of rubberised bitumen binders in United States have reported many advantages characteristics like improved resistance to rutting due to high viscosity, high softening point and better resilience, improved resistance to surface initiated, reduce fatigue/ reflection cracking, reduce temperature susceptibility, improved durability, lower pavement maintenance costs, and saving in energy and natural resource by using waste products (Liu et al., 2009).

According to Ibrahim et al. (2009) Malaysia production of scrap tyres is about 10 million pieces per annum and they are currently being disposed in an environmentally unfriendly manner. A conventional bitumen 80/100 penetration grade is commonly used in Malaysia and it is subjected to the high traffic load and hot weather. Using of crumb rubber in bitumen modification considered as a sustainable technology which transforms an unwanted residue into a new bituminous mixture highly resistant to rutting and fatigue. Since bitumen is viscoelastic material, its rheological properties are very sensitive to temperature as well as rate of loading. The improvement of the properties of rubberised bitumen likely depends on the interaction between crumb rubber and bitumen binder where crumb rubber modifier (CRM) particles swell in the

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bitumen binders to form a viscous gel; resulting in an increase in the viscosity of the rubberised bitumen (Airey et al., 2003; Zanzotto and Kennepohl, 1996; Yildirim, 2007; Jeong et al., 2010; Bahia and Davis, 1994). In addition, rheology can be defined as a material property describing mechanical behaviour under various deformation conditions when materials display abilities to flow and recover their original shape after deformation (Widyatmoko and Elliot, 2008). However, the properties of rubberised bitumen binders at a wide range of temperature are largely depending on the chemistry of the bitumen binder, the crumb rubber percentage, particle size, and texture service, blending temperature and blending time. From the previous literature, it was concluded that swelling of the rubber particles due to the absorption of the light fractions oil and stiffening of the residual binder phase are the main mechanism of the interaction (Airey et al., 2003; Abdelrahman and Carpenter, 1999; Shen and Amirkhanian, 2005). Another study by Katman et al. (2005a, 2005b) on using crumb rubber in porous asphalt showed that the blending procedure and mixing type also affect the performance of the rubberized porous asphalt. From an environment and economic standing point, the use of ground tyre rubber as bitumen – modifying agent may contribute to solving a waste disposal problem and to improving the quality of road pavement. The main objective of this research study is to investigate the effect of various crumb rubber content on the physical, rheological properties and rutting resistance of rubberised bitumen through selected binder tests.

EXPERMMENTAL PROGRAM

Materials

Bitumen binder grade 80/100 penetration was used in this study. This binder has wide use in different areas especially in Malaysia, the physical properties of this binder given in Table 1. The crumb rubber modifier (CRM) produced by mechanical shredding at ambient temperature was obtained from (Rubberplas Sdn. Bhd.) passing the 30-mesh sieve used with chemical components as shown in Table 2.

Preparation of rubberised bitumen binder

The rubberised bitumen binder was prepared in the laboratory at blending temperature of 180 °C (Navarro et al., 2004) and blending time of 60 min (Jeong et al., 2010). Five different concentrations of crumb rubber were prepared by first heating the bitumen to 180 °C. Upon reaching 180 °C, a weighted amount of rubber (4, 8, 12, 16 and 20% by weight of bitumen binder) were slowly added to the original bitumen while mixing at 180 °C using the propeller blade mixer at a blending speed of 200 rpm for blending times of 1 h.

Experiments

Standard laboratory tests for this research were used, namely, penetration test (ASTM D5), ductility test (ASTM D 113), elastic

Table 1. Properties of the base bitumen binder.

| Test properties | Results |
|----------------------------|---------|
| Viscosity at 135°C (Pa.s) | 0.65 |
| G*/ sin δ at 64°C (kPa) | 1.35 |
| Ductility at 25°C (cm) | >100 |
| Softening point (°C) | 47 |
| Penetration at 25°C (d-mm) | 88 |

Table 2. Chemical components of crumb rubber used in the study.

| Major rubber components | Tire rubber |
|----------------------------|-------------|
| Acetone extract (%) | 11.0 |
| Rubber hydrocarbon (%) | 50.5 |
| Carbon black content (%) | 32.5 |
| Natural rubber content (%) | 34.0 |
| Ash content (%) | 6.0 |

recover test (ASTM D 6084) and dynamic shear rheometer (DSR) (ASTM D-4 proposal P246). Penetration, ductility and elastic recovery tests were conducted at temperature of 25°C, while the rheological parameters of DSR test were conducted at temperature of 76°C and the oscillation chosen is 1.59 Hz (10 rad/s) as this is meant to simulate the shear stress corresponding to traffic speed of 90 km/h (55 mph).

RESULTS AND ANALYSIS

Ductility test results

The ductility test was conducted in accordance with ASTM D113. It provides a measure of tensile properties of bituminous materials. The ductility is measured by the distance in centimetres to which standard specimen will elongate before breaking. The ductility result was conducted at 25°C for different crumb rubber contents as illustrated in Figure 1 that shown there is a dramatically decrease in ductility values.

The averages decreased in ductility of modified binder samples compared with unmodified binder were about (18 and 57%) for crumb rubber content of 4 and 20% respectively. In addition, the high amount of crumb rubber in samples 12, 16 and 20% appears to be linear and have constant effect on modified binder under elongation tensile force with correlation coefficient $R^2 = 0.9991$. These results could be explained by the physical interactions during the blending process of the rubberised bitumen.

Accordingly, an increase in binder mass could make the binder more elastic, stiff and highly resistant to pavement rutting. Meanwhile, the decrease in ductility value could be attributed to the oily part of the bitumen

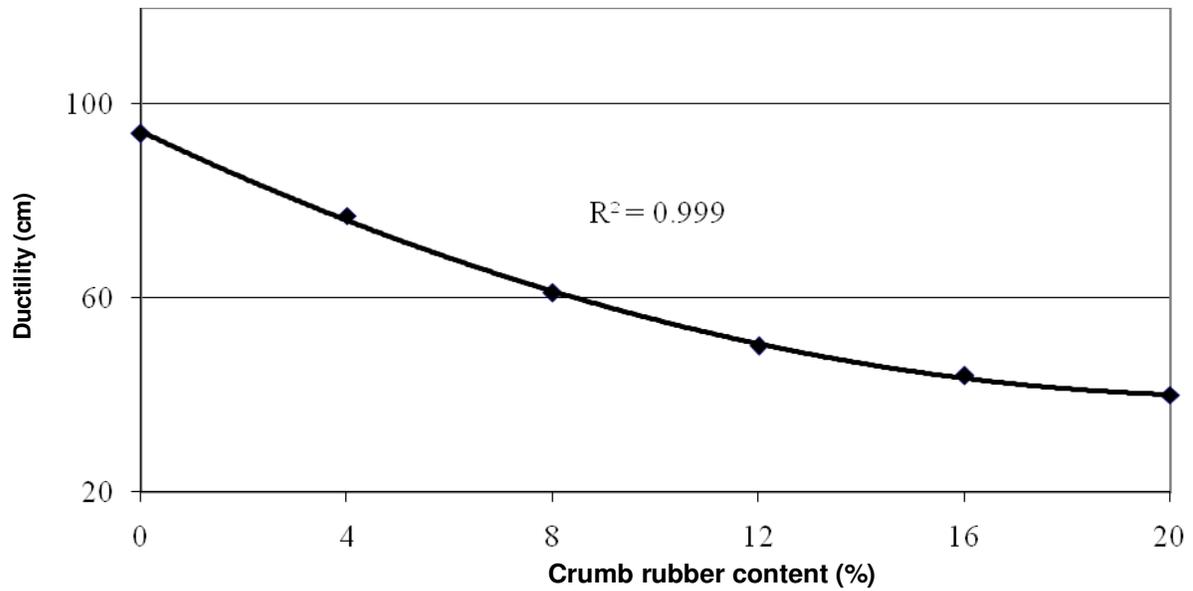


Figure 1. Ductility test results for different crumb rubber content.

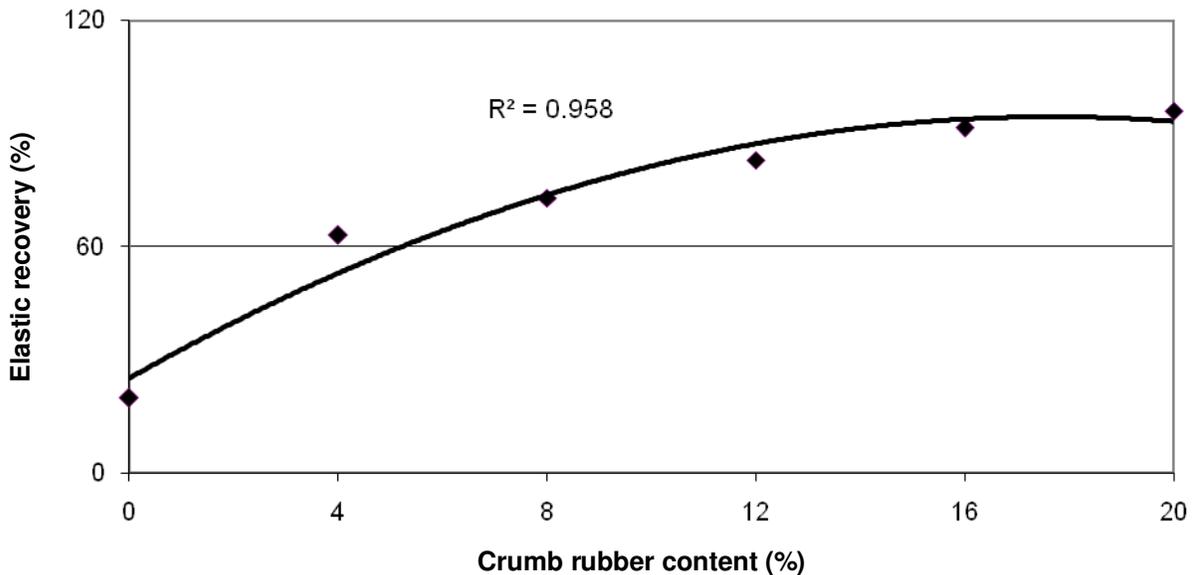


Figure 2. Elastic recovery test results for different crumb rubber content.

absorbed into the rubber powder and the increase in mass of the rubber particles. In effect, the modified binder became thicker compared with the unmodified bitumen samples (Figure 1).

Elastic recovery results

The elastic recovery method test was conducted in

according to ASTM D 6084 at 25°C. Figure 2 shows the effect of different crumb rubber contents on elastic recovery. The increase of crumb rubber content has a significant effect on modified bitumen binder, and it shows a linear increase of elastic recovery value of all samples of rubberised bitumen. Figure 2 illustrate the linear increased in elastic recovery as $R^2 = 0.95$ which ranges between 21 and 88% for CRM content between 4 and 20% respectively.

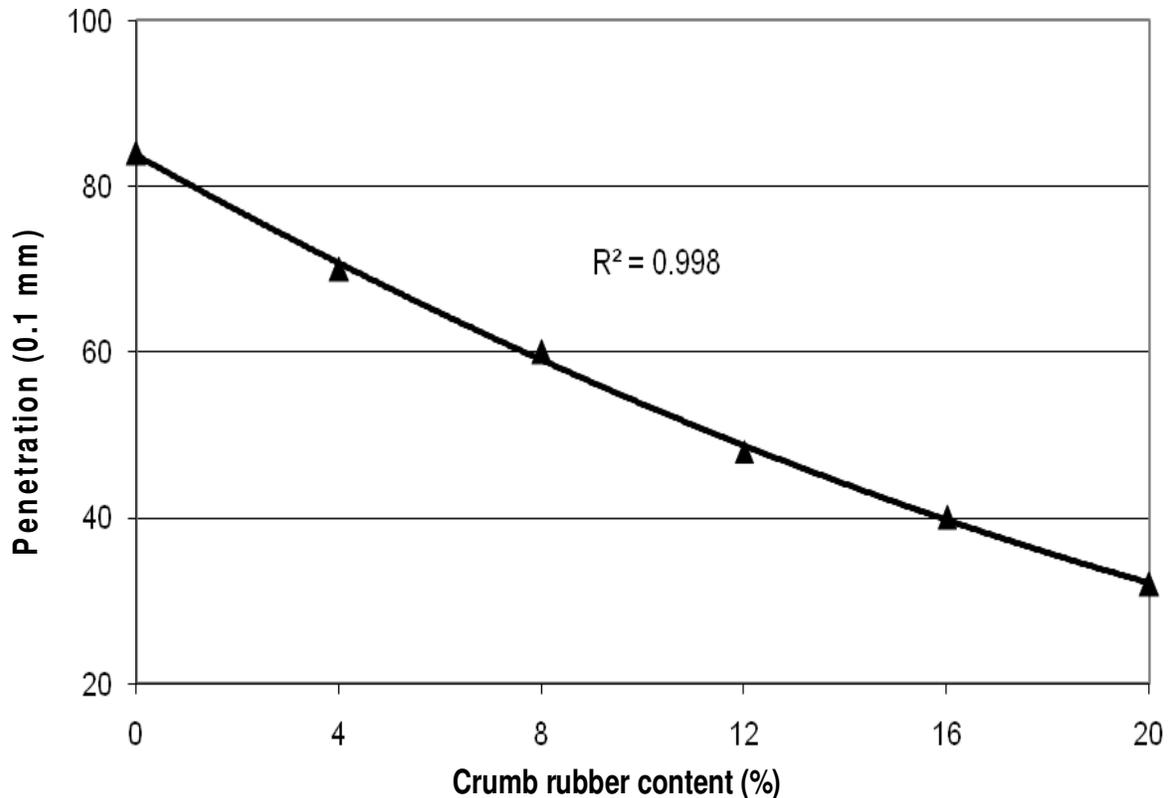


Figure 3. Penetration test results for different crumb rubber content.

Elastic recovery results were similar to ductility results of rubberised bitumen as it shows significant effect of high content of crumb rubber on the modified binder, which presented consistency with binder elasticity and recovery after deformation, hence improving binder resistance to rutting. The elastic recovery values increased from 16.38% for the unmodified binder to 94.5% for the 20% crumb rubber content by binder weight, indicating the ability of the binder to recover its shape after removing the strain load. In general, the crumb rubber consists of elastomers (natural and synthetic rubber); it is well known that synthetic rubber increases the elastic behaviour of the bitumen-modified binder, while the use of natural rubber leads to increase in thermal behaviour (Memon and Chollar, 1997).

Penetration test results

Figure 3 shows the effect of crumb rubber concentration on penetration. The penetration decreased as the amount of rubber increases up to 20%. It shows that CRM content has a significant effect on penetration value. The crumb rubber content has a strong effect on reducing the penetration value by increasing the stiffness of crumb rubber bitumen binder, thus, would make the binder less

temperature susceptible and lead to high resistance to permanent deformation like rutting as mentioned by (Liu et al., 2009). The average reduction in penetration value of modified binder was between 16.5 and 61% for crumb rubber content ranging between 4 and 20% respectively. In addition, Figure 3 shows the linear dramatic decrease in penetration as correlation coefficient $R^2 = 0.99$. This behavior is justified because the rubber addition turns the bitumen more viscous. This increase in rubber content lead to enhanced the particle size of the rubber. This was due to the increase in rubber mass through the interaction and swelling of the rubber into the bitumen during the blending process, which led to the decrease in the penetration of rubberized bitumen. Thus, indicate that the rubberized bitumen binder will be less susceptible to high temperature change and more resistance to rutting.

Dynamic shear rheometer results

Figures 4 to 8 have shown the results of dynamic shear rheometer at 76°C for different crumb rubber content. Dynamic shear rheometer (DSR) was used to measure and determine the rheological properties of the bitumen binder. DSR results included parameters of complex

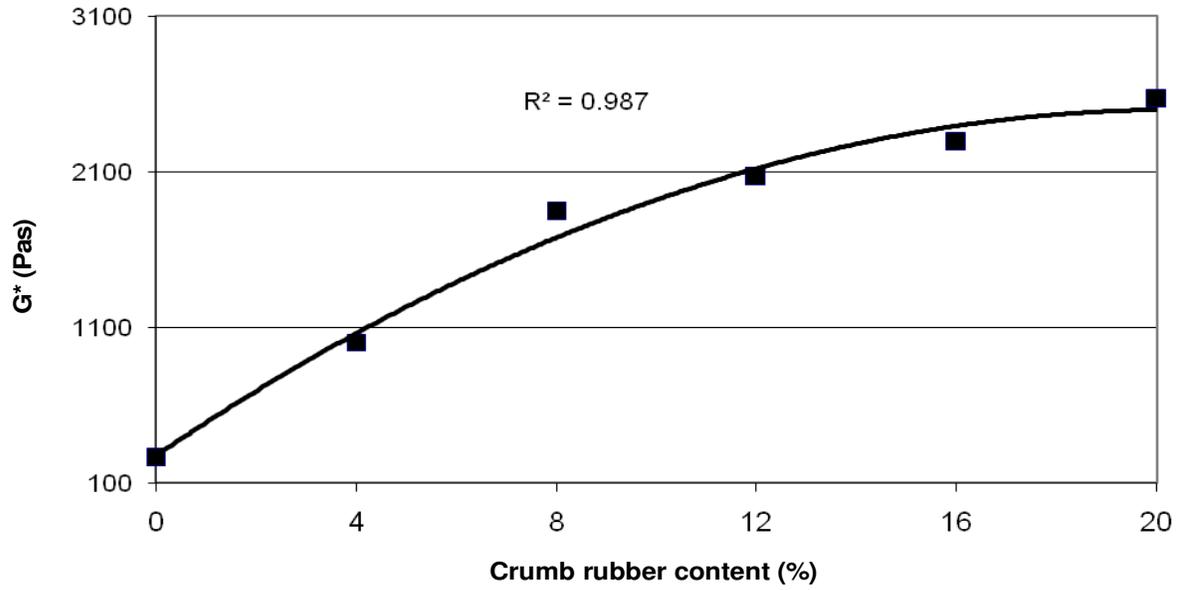


Figure 4. Complex shear modulus results for different crumb rubber content.

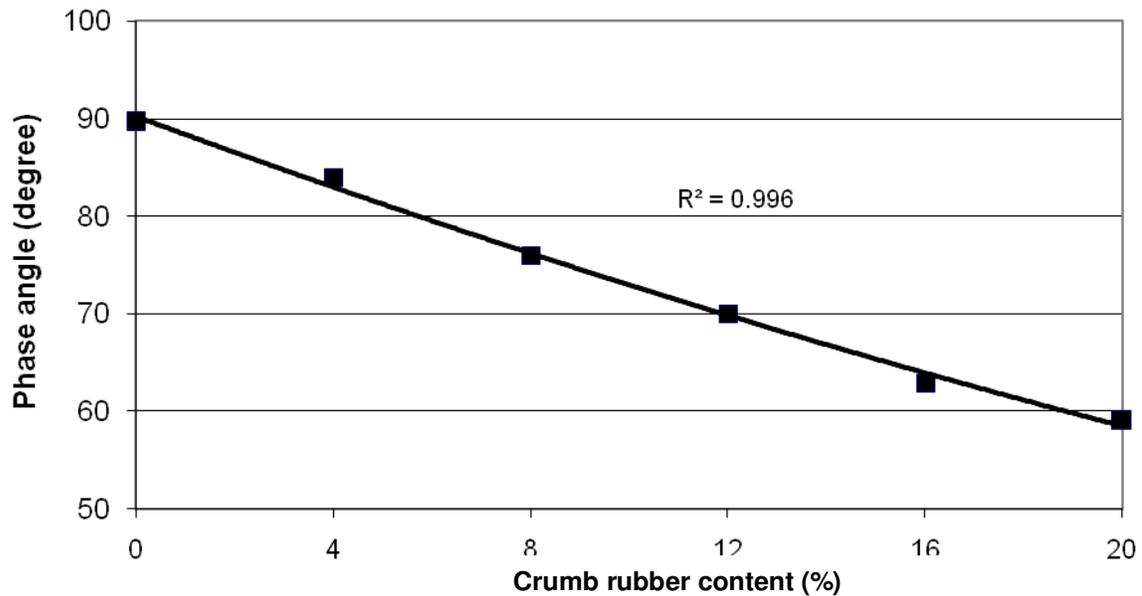


Figure 5. Phase angle test results for different crumb rubber content.

shear modulus (G^*), phase angle (δ), storage modulus (G'), loss modulus (G''), and stiffness indicator / rutting factor ($G^*/\sin \delta$). The increase of crumb rubber in the mix has an obvious effect on rubberised bitumen rheology by increasing in the G^* , G' , G'' and decrease in the δ . Figure 4 shows that crumb rubber has a significant effect on complex shear modulus. The increase in G^* values ranges between 28 and 87% for crumb rubber content

between 4 and 20% respectively. These indicate that crumb rubber addition up to 20% enhances the mechanical properties of the rubberised bitumen.

Figure 5 shows the linear effect of crumb rubber content on phase angle. The average reduction in phase angle of rubberised bitumen samples ranges between 6 and 48% for rubber content between 4 and 20% respectively. The increase in storage modulus G' (elastic

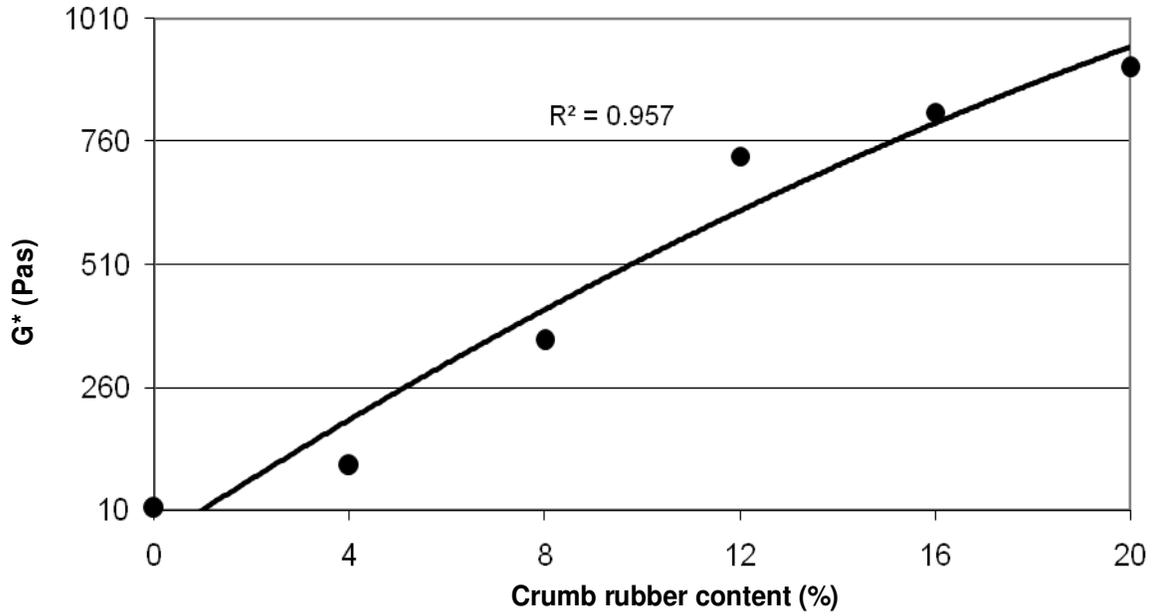


Figure 6. Storage modulus test results for different crumb rubber content.

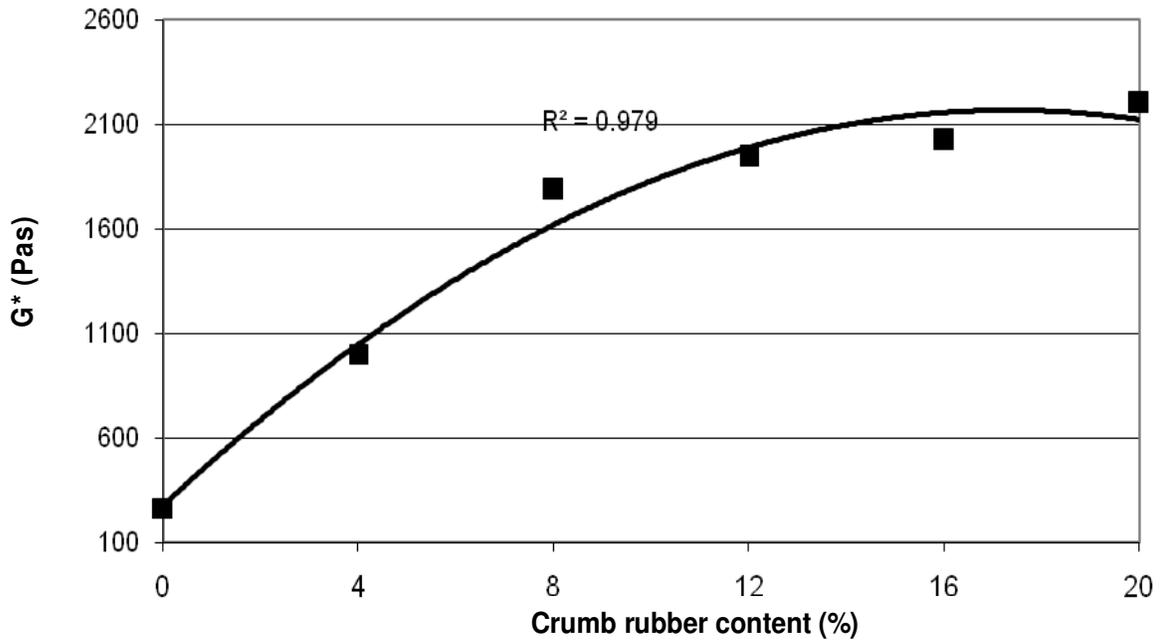


Figure 7. Loss modulus test results for different crumb rubber content.

component) is almost linearly related to the increase in crumb rubber content (Figure 6). The increase in loss modulus G'' (viscous component), however, appears to asymptote at a maximum value as the crumb rubber content increases (Figure 7). At 20% crumb rubber content the storage modulus and loss modulus of

modified binder were increased by about 64% and 74% respectively. As the phase angle is a measure of the ratio between loss modulus and storage modulus ($\tan \delta = G''/G'$), the results obtained for the rheological characteristics are found to be consistent.

Figure 8 shows the result of rutting factor $G^*/\sin(\delta)$ at

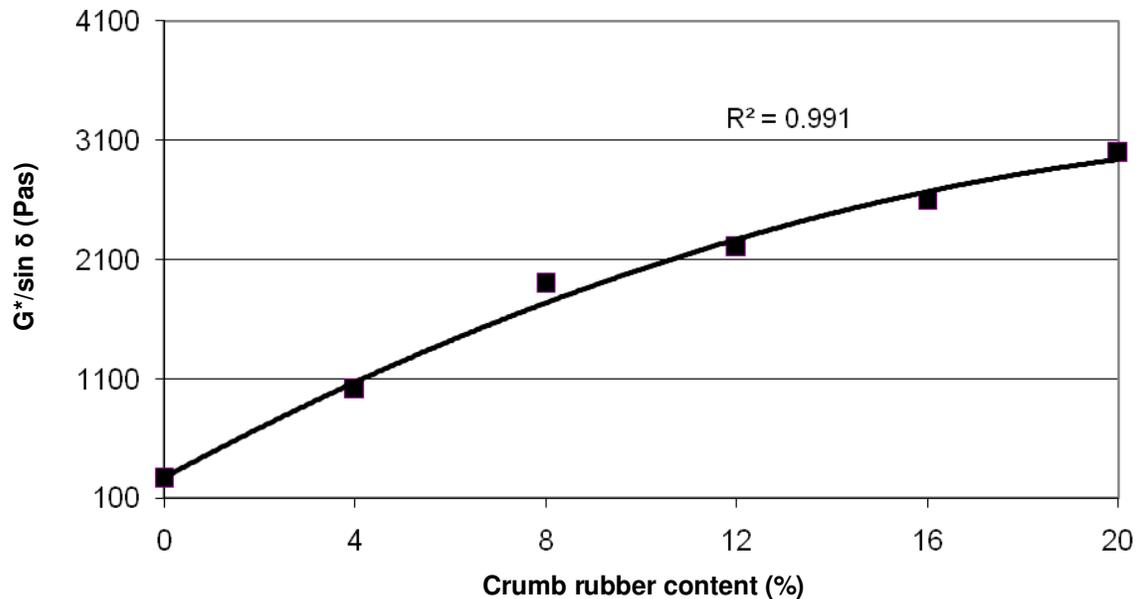


Figure 8. Rutting factor ($G^*/\sin \delta$) results for different crumb rubber content.

76°C for different rubber contents. The addition of crumb rubber has a positive effect on the rutting factor which is an important indicator for rutting resistance. The average percentage increase in rutting factor ranges between 29 and 82% for crumb rubber content between 4 and 20%, respectively.

Conclusion

Based on the results of this study, the addition of crumb rubber to the bitumen binder enhance the physical properties of rubberised bitumen binder as indicated by the reduction in penetration value and ductility, and an increase in the elastic recovery, thus enhancing rubberized binder elasticity and increase its ability to resist rutting deformation. The higher crumb rubber concentration has an obvious effect on rheological properties of rubberised bitumen with increased complex modulus, storage modulus, loss modulus and decreased phase angle. The addition of crumb rubber in bitumen positively affects the rutting factor, thus, enhancing the rutting resistance of the rubberised pavement mix. As evidenced, the high correlation coefficient values are reasonably indicative of an acceptable level of consistency on the effect of crumb rubber content on the physical and rheological properties of rubberised binder.

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