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Transportation Research Procedia 00 (2018) 000–000

Transportation Research Procedia

www.elsevier.com/locate/procedia

World Conference on Transport Research - WCTR 2019, Mumbai, 26-31 May 2019

Influence of Recycled Acrylonitrile Butadiene Styrene (ABS) on the Physical, Rheological and Mechanical Properties of Bitumen Binder

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Abstract

This paper presents a laboratory study of bitumen binder modified with recycled acrylonitrile butadiene styrene (ABS) polymer. ABS has been blended in the bitumen in variegated percentages from 1 to 5% with an increment of 1%. The physical and rheological properties of unmodified and modified binder were investigated using penetration test, softening point test, viscosity test and dynamic shear rheometer (DSR) test. The result indicated an increase in softening point, dynamic viscosity and decrease in penetration up to 4% modifier content and then follows the reverse trend. The blending of bitumen with ABS also increased the rutting resistance parameter ($G^*/\sin\delta$) and reduced the phase angle indicating an improvement in high temperature performance of bitumen binder along with improvement in its elastic properties. The stripping properties of the modified binder also get improved. The best improvement in the modified binder was obtained with 4% ABS additive. The Marshall stability value also significantly improved at this additive content.

Keywords: Acrylonitrile Butadiene Styrene (ABS), Complex shear modulus, Phase angle, Rutting resistance parameter, Marshall stability.

1. Introduction

Electronic waste or e-waste consists of those waste obtained from electronic and electrical appliances which have become unwanted, non-working, or have reached their end-of-life period and are destined for recycling or disposal. It includes discarded computers, printers, television sets, mobile phones etc. Globally, about 20-50 MT (million tons) of e-waste is disposed of every year. By 2020, e-waste from old computers would jump by 400% to 2007

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levels in China and by 500% in India. Additionally, e-waste from discarded mobile phones would be about seven times higher than 2007 levels and in India 18 times higher by 2020 (Agnihotri, 2011).

Electronic substances generally contain hazardous substances, and hence the landfill disposal of e-waste possesses problem due to leaching of heavy metals into the ground water and incineration causing hazardous material airborne and thus the reuse of electronic devices (recycling) is needed. However, the number of times a product can be recycled is limited such as ABS materials or product which is a common component in electronic devices can be recycled atmost three times only (Salleh, 2013). Thus, there is consequently a greater need to develop applications using recycled polymers such as ABS (Palos et al., 2001).

Majority of the roads in India are flexible pavement, the top surface of which have bituminous surfacing (Panda & Mazumdar, 1999; Pareek et al., 2012; Eriskin et al., 2017; Saha & Suman, 2017; Singh & Suman, 2018). Bituminous pavements are susceptible to rutting at high temperature, thermal cracking at low temperature and fatigue cracking at intermediate temperature under repetitive heavy traffic load (Munera & Ossa, 2014; Soudani et al., 2016; Erkus et al., 2017; Kok et al., 2017; Saha & Suman, 2017; Jeffry et al., 2018; Singh & Suman, 2018). Due to early occurrence of these distresses, failure of pavement takes place much before the estimated design life, and huge amount of money is wasted every year for their maintenance.

Acrylonitrile Butadiene Styrene (ABS) is a thermoplastic polymer and can be obtained from recycled e-waste plastics. Thermoplastic polymers, thermosetting plastics, rubbers and block copolymers are usually used to modify bitumen binder with intent to improve the performance of the bitumen (Aksoy et al., 2005).

Colbert & You (2012) reported that the use of Acrylonitrile Butadiene Styrene (ABS) and High Impact Polystyrene (HIPS) e-waste as an additive increased the viscosity, blending and mixing temperature and decreased the rutting susceptibility of the bitumen binder.

Hasan et al. (2016) reported that the use of use of 5% Acrylonitrile Butadiene Styrene (ABS) and Acrylonitrile Butadiene Styrene-Polycarbonate (ABS-PC) e-waste significantly improved the elastic and viscous modulus of the bitumen binder. However, the use of High Impact Polystyrene (HIPS) as an additive was not found to be much effective.

In this study, the modification of bitumen was done by recycled Acrylonitrile Butadiene Styrene (ABS) polymer. This paper presents the effect of introduction of ABS polymer on the physical, rheological and mechanical properties of the bitumen binder.

2. Materials and method

2.1 Bitumen

VG 30 grade of bitumen was used for this study. Its physical properties are shown in Table 1.

Table 1. Properties of VG 30 grade bitumen.

Properties	Value
Penetration 0.1 mm, 100 g, 25 °C, 5s	68.5
Softening point (°C)	53.5
Viscosity at 135 °C (Pa.s)	0.38

2.2 Acrylonitrile Butadiene Styrene (ABS)

Recycled ABS was used in powdered form as an additive for the modification of the bitumen binder. ABS in powdered form is shown in Fig. 1 and its physical properties are shown in Table 2.

Fig. 1. Recycled Acrylonitrile Butadiene Styrene.

Table 2. Basic properties of ABS.

Physical state	Fine grained powder
Colour	White
Chemical formula	$(C_8H_8.C_4H_6.C_3H_3N)_n$
Density	1.060-1.080 g/cc
Poissons ratio	0.35
Particle size	<375 µm

2.3 Preparation of polymer-bitumen blend

Bitumen binder was heated to a temperature of 165±5 °C. Then, ABS powder was mixed at five different percentages i.e 1, 2, 3, 4 and 5% by weight of bitumen and stirred mechanically in a shear mixer at a speed of 2000 rpm and at a temperature of 165 °C for 30 minutes in order to ensure the well dispersion of additives in the bitumen.

2.4 Test program

Conventional bitumen tests such as penetration and softening point were carried out as per the guidelines of IS: 1203-1978 and IS:1205-1978 respectively. The viscosity test was carried out using rotational viscometer as per the guidelines of ASTM D4402. The dynamic shear rheometer (DSR) test was carried out as per the guidelines of ASTM D7175. The stripping test was carried out as per the guidelines of IS: 6241-1971.

3. Results and discussion

3.1 Penetration test

Fig. 2 shows the result of penetration test performed on virgin and ABS modified samples. The modified bitumen showed an improvement in the penetration value as compared to the virgin sample. The penetration value reduced by 21.75%, 30.07%, 39.66% , 59.71% and 41.90% as compared to the virgin sample for 1%, 2%, 3%, 4% and 5% ABS modified samples respectively. The minimum value of penetration was found at 4% ABS content.

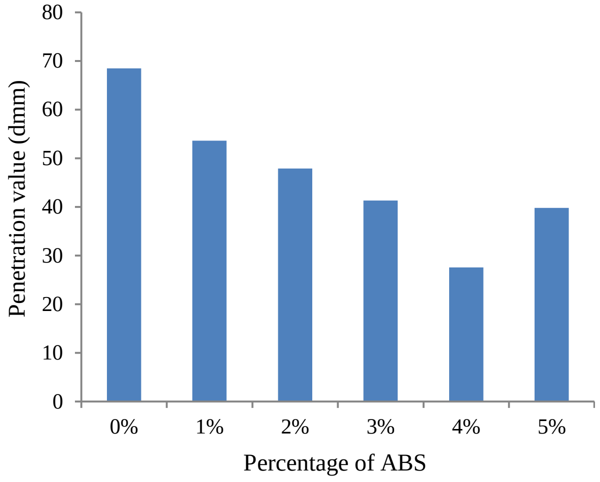

Fig. 2. Effect of ABS on penetration.

3.2 Softening point test

Fig. 3 shows the result of softening point test performed on virgin and ABS modified samples. The modified bitumen showed an increment in softening point value as compared to the virgin sample. The softening point value increased by 37.38%, 41.12%, 44.86%, 56.07% and 48.60% respectively as compared to the virgin sample for 1%, 2%, 3%, 4% and 5% ABS modified samples respectively. The maximum value of softening point was found at 4% ABS content.

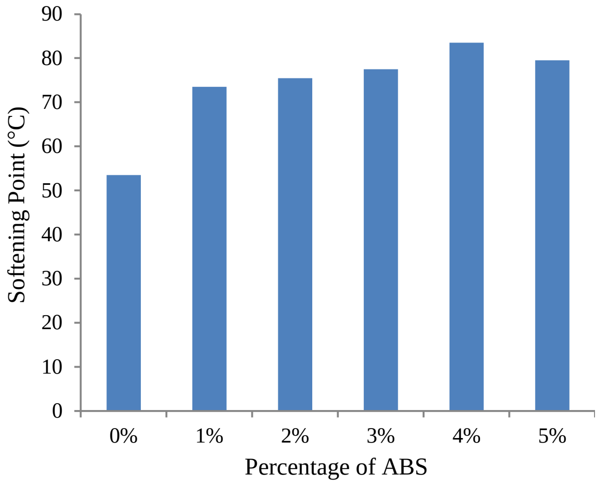

Fig. 3. Effect of ABS on softening point.

3.3 Viscosity

Fig. 4 shows the result of viscosity test performed on virgin and ABS modified samples. The modified bitumen showed an increment in viscosity value up to 4% ABS content and then follows the reverse trend. Also, the value of viscosity decreases with the increase in temperature as shown in Fig. 5. The viscosity value increased to 1.5 Pa.s for 4% ABS modified sample from 0.38 Pa.s for the virgin sample at 135 °C. Also, the viscosity value of virgin and

ABS modified samples are within the maximum permissible limit of 3 Pa.s (Jeffry et al., 2018). The maximum value of viscosity was found at 4% ABS content.

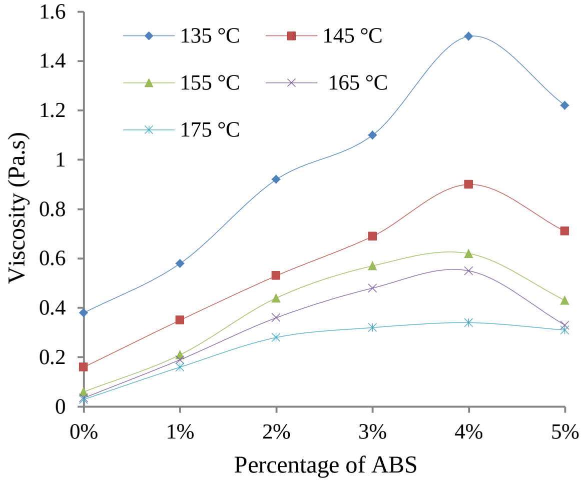

Fig. 4. Effect of ABS on viscosity.

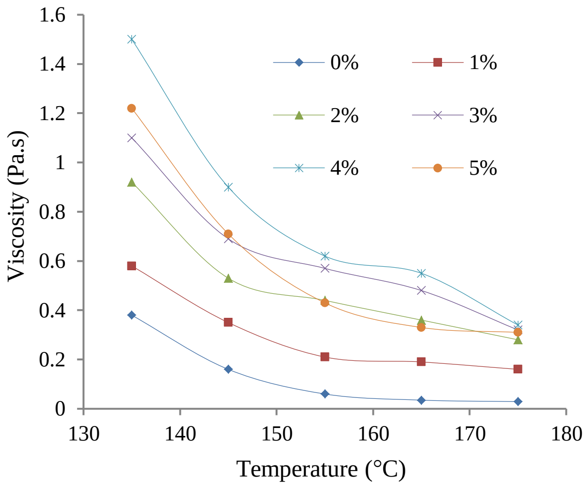

Fig. 5. Variation of viscosity with temperature.

3.4 Rutting performance (G/sinδ)*

Fig. 6 shows the result of DSR test performed on virgin and ABS modified samples performed at 46 °C, 52 °C, 58 °C and 64 °C. The modified bitumen showed an increment in G*/sinδ value up to 4% ABS content and then follows the reverse trend. Also, the value of G*/sinδ decreases with the increase in temperature as shown in Fig. 7. The G*/sinδ value increased to 244.99 kPa for 4% ABS modified sample from 16.264 kPa for the virgin sample at 46 °C. The maximum value of G*/sinδ was found at 4% ABS content.

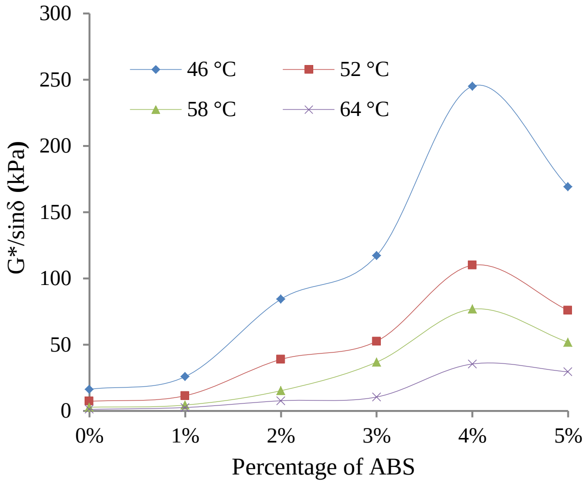

Fig. 6. Effect of ABS on G*/sinδ.

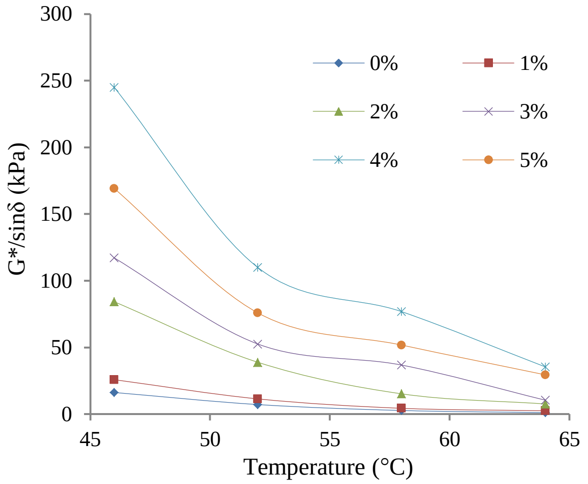

Fig. 7. Variation of G*/sinδ with temperature.

3.5 Phase angle (δ)

Fig. 8 shows the trend of phase angle for virgin and ABS modified samples performed at 46 °C, 52 °C, 58 °C and 64 °C. The modified bitumen showed a decrement in phase angle up to 4% ABS content and then follows the reverse trend. The decrement in phase angle indicates that the elasticity of the modified bitumen gets improved with the increase in the additive content, and thus likely to improve the low temperature performance of mixtures. Also, the value of phase angle increased with the increase in temperature as shown in Fig. 9. The phase angle decreased to 62.5 for 4% ABS modified sample from 82.3 for the virgin sample at 46 °C. The minimum value of phase angle was found at 4% ABS content.

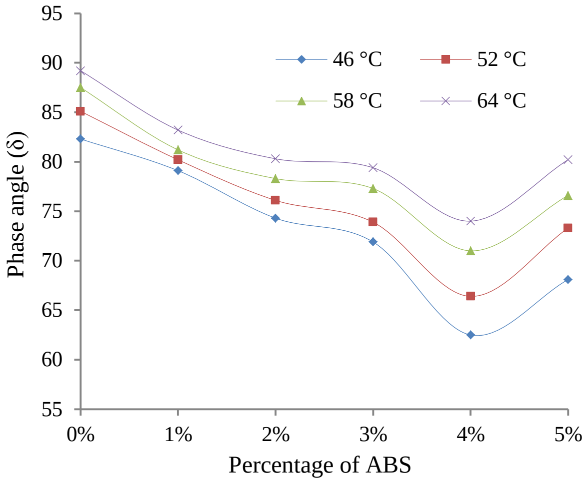

Fig. 8. Effect of ABS on phase angle.

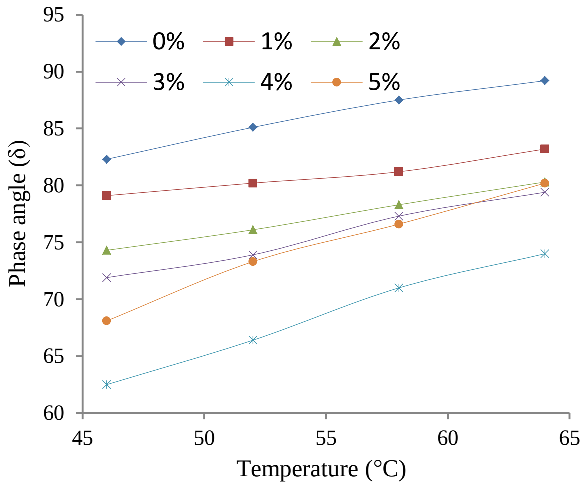

Fig. 9. Variation of phase angle with temperature.

3.6 Stripping test

Fig. 10 shows the result of stripping test performed on virgin and ABS modified samples. The modified bitumen showed an improvement in the stripping value as compared to the virgin sample. The stripping value reduced by 16.67%, 37.50%, 58.33%, 75% and 66.67% as compared to the virgin sample for 1%, 2%, 3%, 4% and 5% ABS modified samples respectively. The minimum value of stripping was found at 4% ABS content.

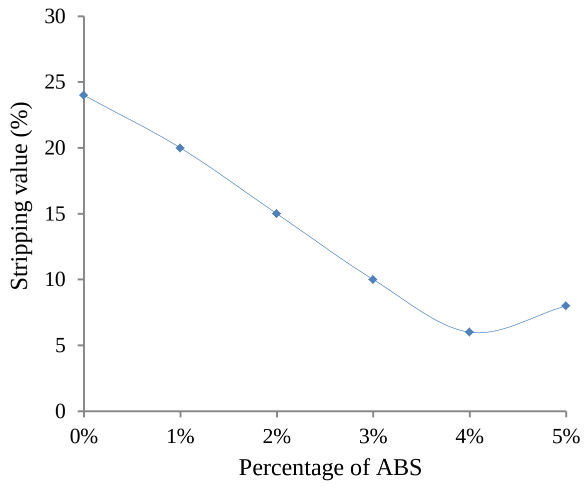

Fig. 10. Effect of ABS on stripping value.

3.7 Marshall stability test

The Marshall stability test was performed as per the guidelines of Ministry of Road Transport and Highways (MORTH). The optimum bitumen content (OBC) obtained for 4% ABS modified bitumen was 5.85%. The stability value rose by 68.77% for 4% ABS modified bitumen as compared to virgin bitumen. The flow value reduced and density increased slightly, whereas the air voids and voids filled with bitumen remains almost unchanged. All the observed values are within the limiting range as specified in Table 3.

Table 3. Marshall Properties at optimum binder contents.

Specification	**Virgin bitumen**	**4% ABS modified bitumen**	**Permissible range**
OBC	5.5	5.85	-
Stability (kg)	967	1632	> 900 kg
Flow (mm)	2.98	2.47	2-4 mm
Density (g/cc)	2.371	2.398	-
V_v	3.81	3.89	3-6%
VFB	74.21	73.82	65-75%

4. Conclusions

The penetration value decreased and softening point increased for ABS modified bitumen samples and maximum improvement was found for 4% ABS content. Thus, the modified binder can be considered suitable to be used in places where climate remains warm.

The viscosity value increased for ABS modified bitumen samples and maximum value was found for 4% ABS content. The increased viscosity results in an increase in adhesion between the binder and aggregate and thus enhancing the performance of the pavement.

The rutting resistance parameter (G*/sinδ) increased for ABS modified bitumen samples and maximum value was found for 4% ABS content. Thus, the modified bitumen improves the high temperature performance of the pavement.

The phase angle decreased for ABS modified bitumen samples and minimum value was found for 4% ABS content. Thus, the modified bitumen binder is likely to improve the low temperature performance of the pavement due to increase in the elasticity of the binder.

The maximum improvement in stripping value was obtained for 4% ABS content. Thus, the modified mix is less susceptible to moisture damage.

Based on the above investigations, the optimum ABS content was found to be 4%. Also, at this optimum content, the stability value increased by 68.77% and the flow value reduced by 17.11% as compared to virgin bitumen, however there was no significant change in other factors. Thus, the mechanical properties also get improved due to the incorporation of ABS additive.

The results show a potential use for recycled ABS materials as a modifier of bitumen binder and the recommended content is 4% by weight of bitumen.

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