

Original Article

# Laboratory Evaluation of Reclaimed Asphalt (RAP) Combined with ABS Extracted from E-waste

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**Abstract** - Due to high consumption of electronic goods in the 21<sup>st</sup> century, the accumulation of E-waste has been found to be high, and it is on an increasing trend. On the other hand, the researchers are focusing on developing high-performance pavement to cater to heavy traffic and high axle load, which allows the researchers to evaluate the possibilities of incorporating the E-waste as a modifier on fresh and aged bitumen to develop the high-performance asphalt. In this research, the virgin bitumen and reclaimed aged bitumen of ages 4, 6, and 8 years were partially replaced by ABS obtained from E-wastes. The physical properties are evaluated and compared using FTIR and a Fluorescent optical microscope. The Rheological parameters evaluated are Penetration value, Kinematic viscosity, Complex shear modulus, and rutting parameter ( $G^*/\sin\alpha$ ). The mechanical properties of fatigue life and rutting resistance are compared. According to the study's findings, bitumen that has been aged and reclaimed and contains ABS performs better than regular bitumen. On the other hand, the mechanical, rheological, and physical properties of the virgin bitumen treated with ABS were at their best.

**Keywords** - E-waste, Fatigue, Rutting, Sustainable, Recycle, Asphalt Mix.

## 1. Introduction

Modification of conventional asphalt by the polymers began in the late 20th century [1, 2]. Important components included in e-waste ensure the recycling of all of its components. Although plastic is neither the primary residue nor the most polluting material in this type of e-waste, it does take up a lot of space because of its low density and form. Plastic makes up around 18% of the weight of e-waste, primarily thermoplastics that may be recovered through further processing. [3]. Researchers were driven to conduct extensive research because of the engineering behavior, morphology, and cost of certain polymers, such as ethylene-vinyl acetate and styrene butadiene-based polymer, which enhanced properties like resistance to rutting, fatigue life, complex shear modulus, and temperature resistance. [4, 5]. Specifically, while working with HIPS/ABS blends of virgin resins, it is conjectured that the respective concentrations of styrene, butadiene, and acrylonitrile (for ABS) in each copolymer at the relative HIPS/ABS concentration will determine the phase separation. They also heavily depend on the composition and dimensions of the PB phase and are mostly impacted by mechanical qualities. [6]. In ABS and HIPS virgin resins, the dispersed PB phase can therefore function as an “auto-compatibility improver” in the blends,

enhancing phase adherence and thereby enhancing mechanical performance. [7]. However, such “self-compatibility” may depend on the relative proportion of HIPS/ABS in the mix, as well as the content of Polymer in bitumen. Old bitumen obtained from Recycled Asphalt Pavement (RAP) aggregate should be used to reduce flexible pavement construction costs and landfills of RAP, causing environmental pollution [8]. To reuse in the asphalt mix used in the construction of flexible pavements, scientists thus concentrate on reversing the age of bitumen that is closest to virgin bitumen. [9]. When the bitumen exposed to the atmosphere in the presence of sunlight, uv radiation and moisture content tends to formation of ketones and carbonyl compounds responsible for the reduction elasticity of the bitumen [10] From the literature review, it was found that no research has done on investigate the incorporation of the ABS with aged bitumen ( bitumen exposed to the atmosphere for a period tends to loses its elasticity due to oxidation process). Hence, in this research, the virgin and different years of aged bitumen (different durations of oxidation) modified by ABS modifier to identify the possible application of aged bitumen and E-waste in the flexible pavement construction.



**2. Materials**

**2.1. Virgin Bitumen**

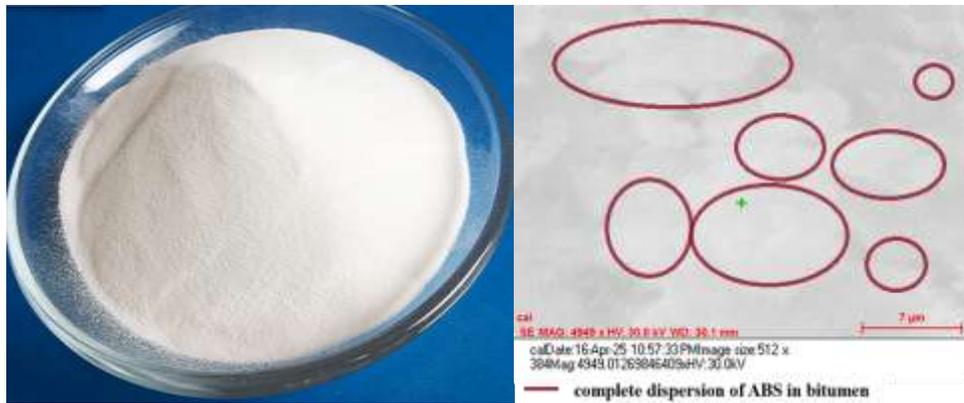
The typical VG-30 (viscosity grade bituminous binder) is susceptible to the following regulations, having a penetration of 50 to 75 mm at 25 °C and a kinetic viscosity of more than 340 cst at 135°C: picked in accordance with the guidelines' specifications. The climate conditions that apply to the majority of India are based on IS 73 2013. ASTM E 73 2013 states that VG-30 is a Super Pave Performance Class (PG 64-16) binder. [11].

**2.2. E-Waste**

The acrylonitrile-butadiene-styrene, or ABS, made up of three components: Acrylonitrile, Butadiene, and styrene provides resistance to chemicals and high temperature, stability, toughness, and impact resistance, and is easy to

process. It is often used in the construction, automobile, and electronics industries. It contributes significantly to e-waste as well, making up as much as 25% of the plastic material [12].

Therefore, ABS may be obtained by WEEE (Waste from Electrical and Electronic Equipment) mechanical recycling. Electrical and electronic trash is crushed into tiny bits and cleaned to get rid of any contaminants throughout this procedure. Asphalt made from recycled ABS uses fewer natural resources and emits fewer pollutants. [13] ABS is a recyclable material that can help recycle the reclaimed asphalt obtained from the recycled RAP [14]. The physical appearance and SEM image of the ABS is shown in Figure 1(a) and 1(b), respectively. The physical characteristics of the acrylonitrile-butadiene-styrene used in this research are given in Table 1.



(a) Physical appearance of ABS (b) Sem image of ABS mixed with bitumen  
**Fig. 1 Macro and micro structure of Acrylonitrile-Butadiene-Styrene (ABS)**

**Table 1. Physical characteristics of ABS used in this research**

S.No	Physical Characteristic	Value
1	Unit weight	1.5g/cm <sup>3</sup>
2	Fines of ABS	90 to 120 m <sup>2</sup> /g
3	Size of ABS granules	20m to 110nm
4	Temperature resistance	maximum 350°C
5	Morphology	Irregular in shape and porous

**Table 2. Asphalt specimen ID used in this research**

Sl.NO	Asphalt Specimen ID	Bitumen Age	Acrylonitrile-Butadiene-Styrene(%)	Remarks	Observation from Fluorescent Microscope
1	FB	0	0	Fresh bitumen (Reference Mix)	No ABS
2	FBabs	0	4	Modified fresh bitumen with 4%ABS	High concentration of ABS
3	AB4	4	0	Reclaimed asphalt without ABS	No ABS Concentration
4	AB6	6	0		
5	AB8	8	0		
6	AB4abs	4	4	Modified reclaimed asphalt with 4% ABS	High concentration of ABS
7	AB6abs	6	4		Medium concentration of ABS
8	AB8abs	8	4		Low concentration of ABS

### 2.3. Modified Reclaimed Bitumen

Reclaimed bitumen that is four, six, and eight years old was collected for this study using Recycled Asphalt Pavement (RAP) that came from various sources and was subjected to the same environmental conditions, traffic patterns, and loading patterns.

The aged asphalts, along with trichloroethylene, were collected using a rotary bitumen extractor, and the bitumen alone is extracted using a rotary vacuum evaporator shown in Figure 2. The reclaimed bitumen of different ages was modified with the optimum ABS 4% with a high-speed shear mixer to ensure homogeneous mixing of ABS with the aged bitumen [13].



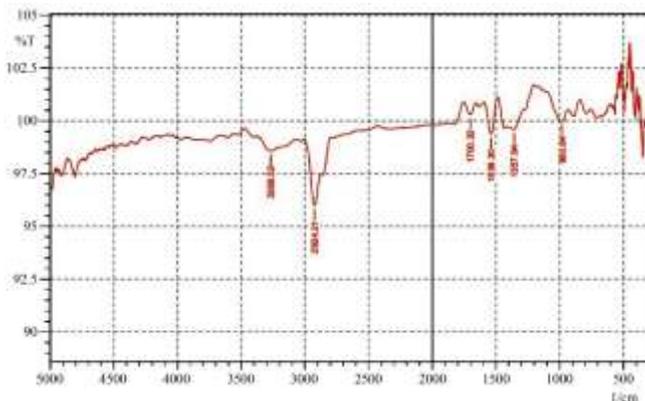
Fig. 2 Rotary vacuum evaporator

### 3. Asphalt Specimen Details

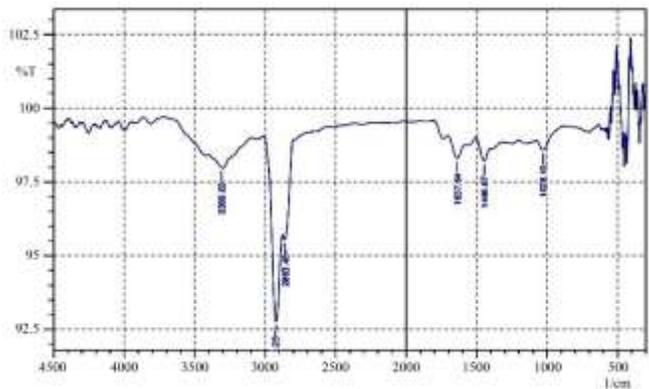
Table 2 provides information on the asphalt mixes that were taken into consideration for this study. Based on fresh bitumen, aged bitumen, and aged modified with 4% ABS percentage, the specimens designated as FB, FBabs, AB4, AB4abs, AB6, AB6abs, AB8, and AB8abs were created. Ex: FB denotes fresh bitumen. Ex: AB4abs, 4 represents the age of reclaimed bitumen, and abs represents the presence of 4% Acrylonitrile-butadiene-styrene.

### 4. Physical Properties

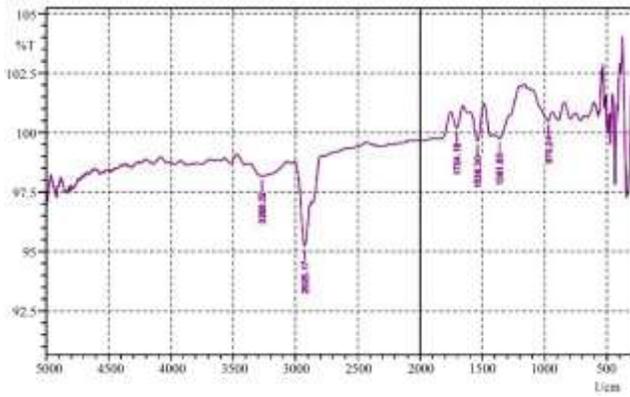
Optical microscopic testing and infrared spectroscopy are used to evaluate the physical characteristics of the asphalt specimen. One of the most popular infrared spectroscopy methods for figuring out the physical interactions between the constituents of modified asphalt and asphalt blends is Fourier Transform Infrared (FTIR) spectroscopy [14]. When comparing the ABS modified bitumen to all of the aged recovered bitumen, Figure 3 makes it evident that new peaks are present. However, the peaks equal to the virgin bitumen are not archived in the presence of ABS in aged bitumen. As the age increases, the recovery ability of the aged bitumen nearest the virgin bitumen property also decreases. The aged bitumen property restrained by the presence of ABS polymer over the bitumen, like swelling and absorption such that the structure and the composition of the bitumen changes due to ABS polymers molecules become embedded in the asphalt matrix leads to changes the chemical composition of the asphalt, thus FTIR spectrum shows new peaks that correspond to the functional groups of the ABS polymer [15, 16]. When ABS polymer is added to asphalt, new chemical bonds are formed in the asphalt material, and new bonds absorb infrared light at different wavelengths than the bonds that are already present in asphalt, which leads to a new peak appearing in the FTIR spectrum of ABS polymer-modified asphalt [17, 18]. The changes are further confirmed by the optical fluorescence microscopy for all the aged reclaimed and aged reclaimed bitumen with ABS, as shown in Figure 4.



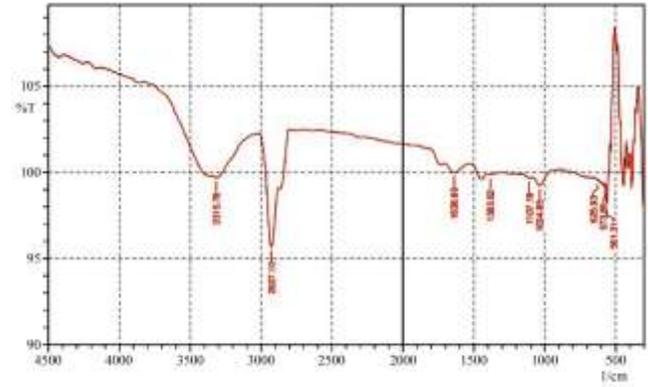
(a) AB4



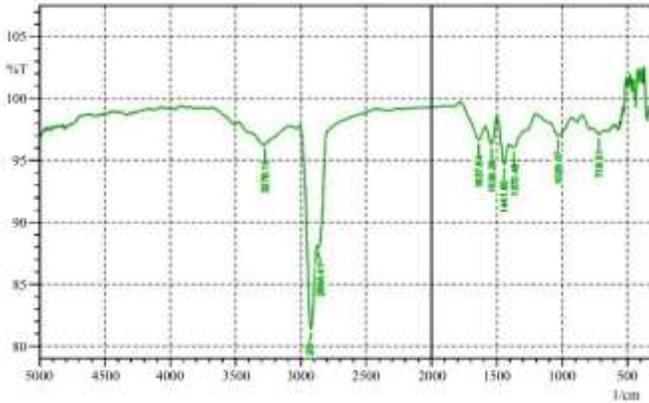
(b) AB4abs



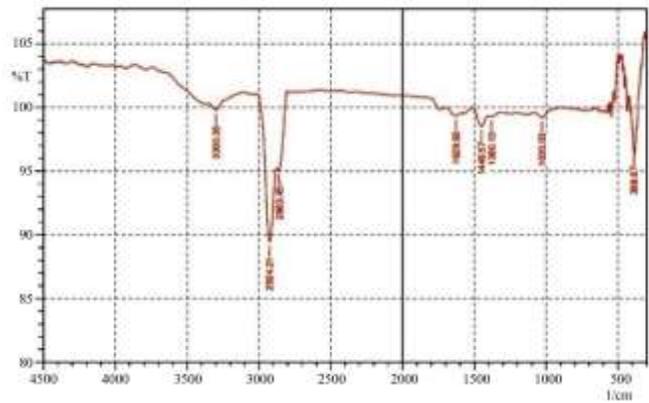
(c) AB6



(d) AB6abs

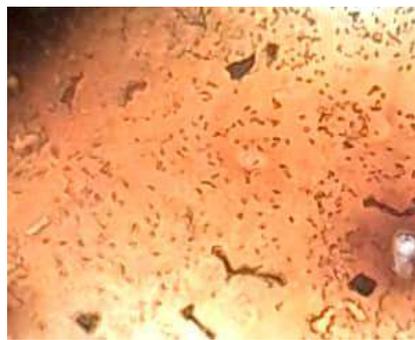


(e) AB8

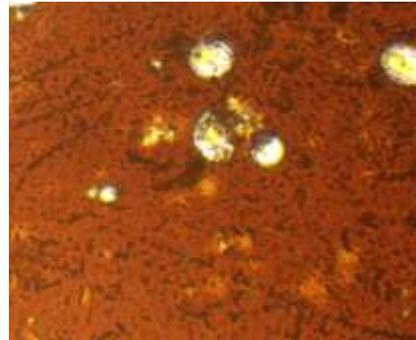


(f) AB8abs

Fig. 3 FTIR spectra of aged bitumen and ABS-modified aged bitumen



(a) AB4 (P)



(b) AB4abs



(c) AB6



(d) AB6abs

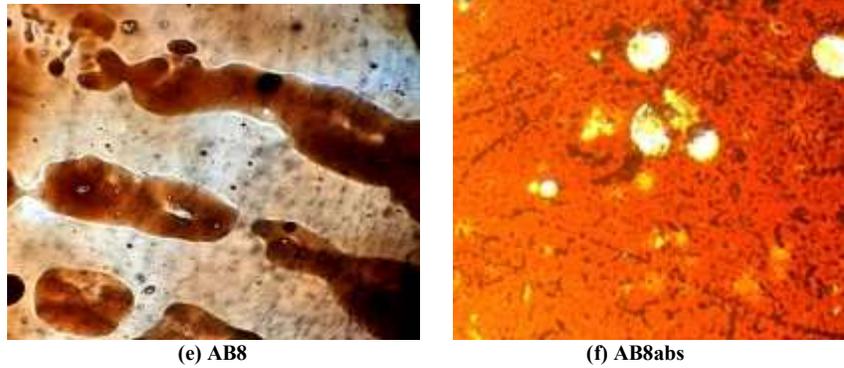


Fig. 4 (a), (b), (c), (d), (e), (f) Flurosent microscopic test results of different asphalt mix.

## 5. Rheological Properties

### 5.1. Penetration and Viscosity Test

The rheological parameters of various asphalt specimens examined in the research supplied in Table 1 are evaluated using the penetration value using a pentrometer according to IS 1203-1978 [19] and the kinematic viscosity value using a Brookfield rotating viscometer conforming to ASTM-D4057, 2022 [20] as shown in Figure 5. The Kinematic viscosity test setup is shown in Figure 5. The VG30 asphalt should have a penetration value between 50mm and 70mm according to IS 73-2013[13]. From Figure 6, it was observed that, for virgin bitumen and all ages of bitumen, the penetration value decreased when asphalt specimens were modified with ABS. Except for the specimen AB8 and AB8abs, all other asphalt specimens have the penetration value that falls within the minimum and maximum limit suggested by IS 73-2013[13]. The decrease in penetration value of asphalt mix with polymer (ABS) due to the formation

of cross-links by polymer between the bitumen molecules, and the polymer acts as a barrier to the flow of asphalt [20-23]. The VG30 asphalt should have a minimum Kinematic viscosity value at 135°C greater than 350 cSt value according to IS 73-2013[13].

From Figure 7, it was observed that, for virgin bitumen and all ages of bitumen, the viscosity value increased when asphalt specimens were modified with ABS. The entire asphalt specimens, the kinematic viscosity value at 135°C falls above the suggested value according to IS 73-2013[13]. The increase in kinematic viscosity at high temperature with ABS polymer is due to the polymer chains converting the asphalt, highly entangling the asphalt molecules, causing resistance to flow, and absorption of heat by the polymer [25-29]. Because of the decreased flow of asphalt, greater rigidity modulus, and lower phase angle, an increase in viscosity enhances the asphalt mix's resistance to rutting [30-33].



Fig. 5 Brookfield viscosity test setups

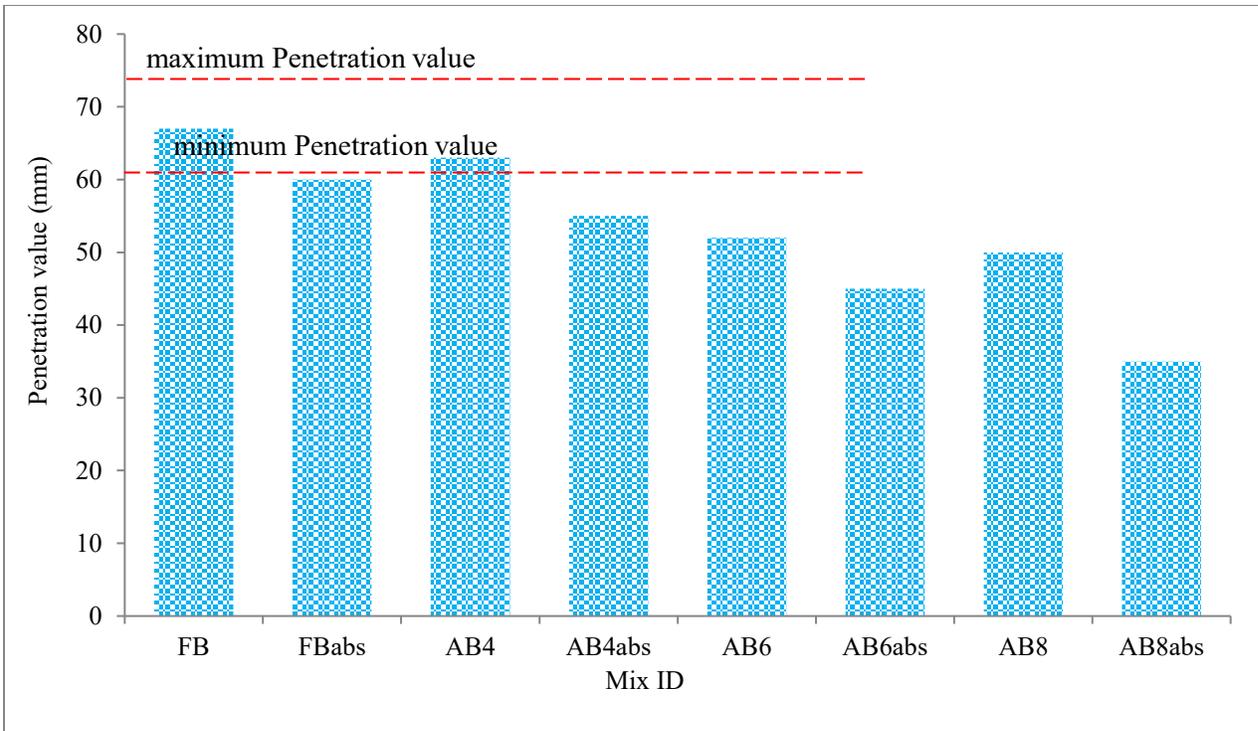


Fig. 6 Variation of viscosity penetration value for different asphalt specimens

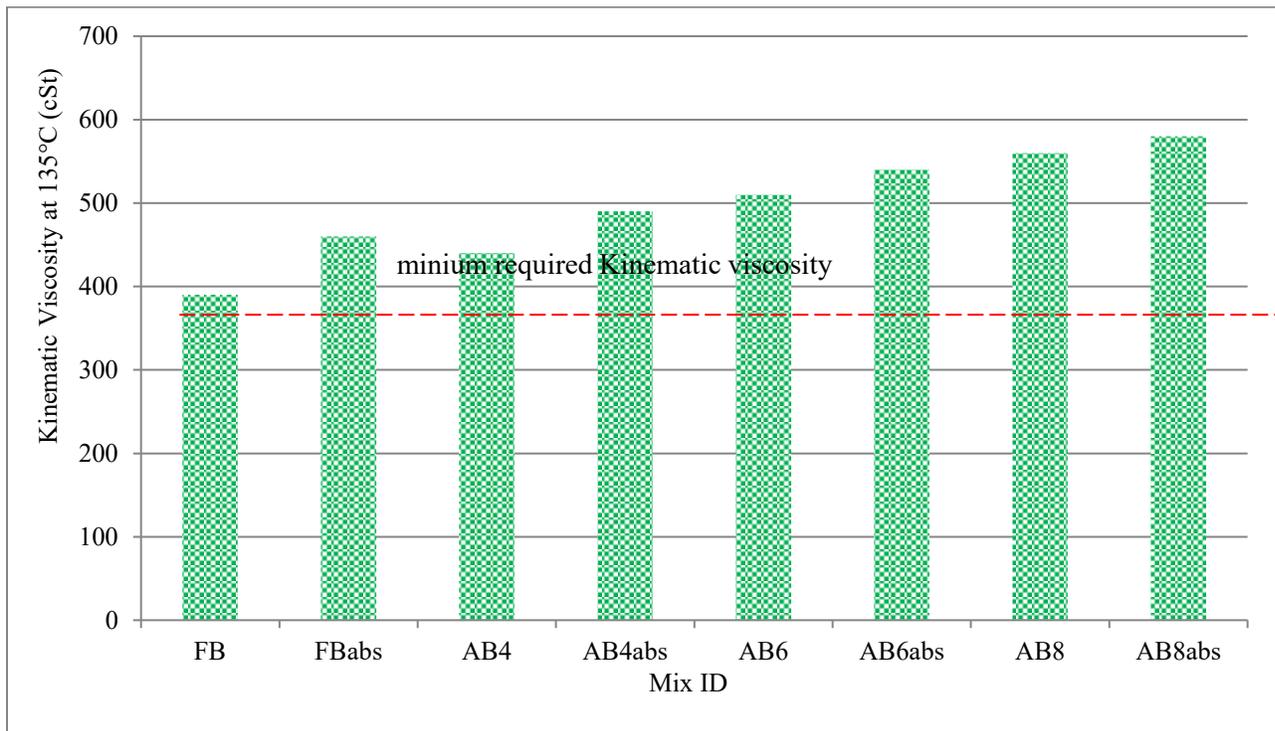


Fig. 7 Variation of kinematic viscosity for different asphalt specimens

### 5.2. Dynamic Shear Rheometer Test

The Dynamic Shear Rheometer equipment was used to assess the performance of asphalt at intermediate to high temperatures in accordance with EN 14770:2012 [33]. The

following rheological parameters, Complex Shear Modulus ( $G^*$ ) and Rutting parameter  $G^*/\sin(\delta)$  (stiffness of asphalt specimen), are derived by acquiring shear stress ( $\tau$ ), deformation ( $\gamma$ ), and phase angle ( $\delta$ ) from the test depicted in Figure 8.

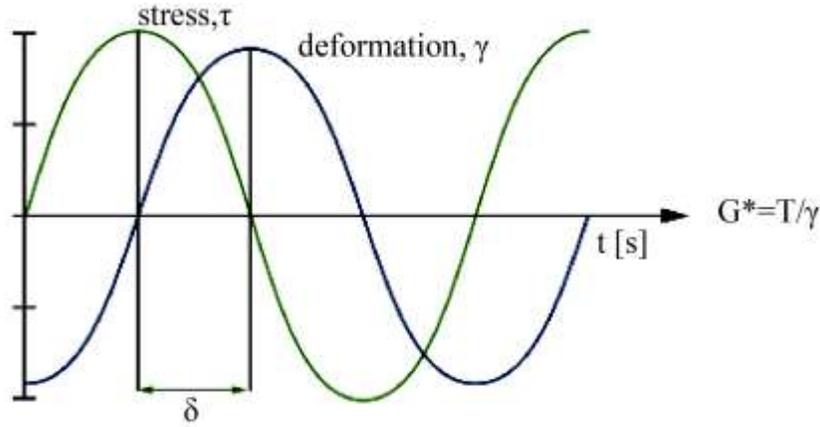


Fig. 8 DSR test- shear stress ( $\tau$ ), deformation ( $\gamma$ ), and phase angle ( $\delta$ )

Figure 9 shows that the complex shear modulus increases with increasing temperature [35-36]. However, ABS-treated asphalt has a larger complex shear modulus than unmodified asphalt. Increase in  $G^*$  at higher temperature due to the asphalt molecules moving freely because of less intermolecular force unable to hold them in both the case of asphalt with polymer and without polymer [37]. At higher temperatures, asphalt molecule tends to move freely, making asphalt less stiff [38], and thermal degradation of the asphalt specimen at higher temperatures [39] leads to less increase in complex shear modulus observed. The rutting parameter  $G^*/\sin\alpha$  was determined for two different temperatures of 46°C and 64°C. From the Figure 10, it was observed that, at higher temperature lower  $G^*/\sin\alpha$  value due to

at high temperatures asphalt binder held together by long chains and weak bond causing less viscous and lower resistance to deformation [40, 41], and at lower temperature higher  $G^*/\sin\alpha$  are noted due to asphalt molecules are more tightly packed together and have less energy to move around at lower temperatures. The tighter packing of the molecules makes it more difficult for them to slide past each other, which results in a higher  $G^*/\sin\alpha$  value. The  $G^*/\sin\alpha$  value was higher for asphalt modified by ABS when compared to all the unmodified asphalt specimens of different ages shown in Figure 10. Due to polymer-modified asphalt, the polymer molecules in the asphalt act as a cross-linking agent, which increases the stiffness and strength of the asphalt [42].

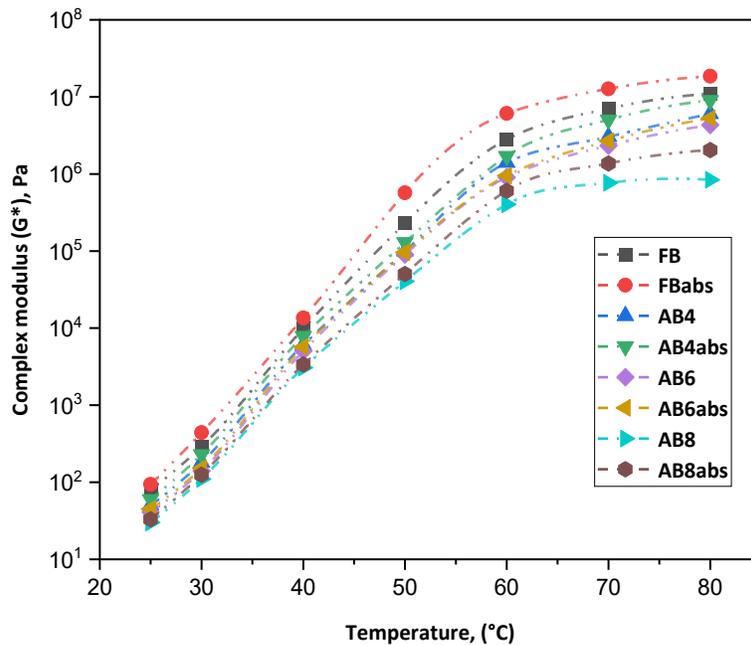


Fig. 9 Variation complex of modulus for different asphalt specimens

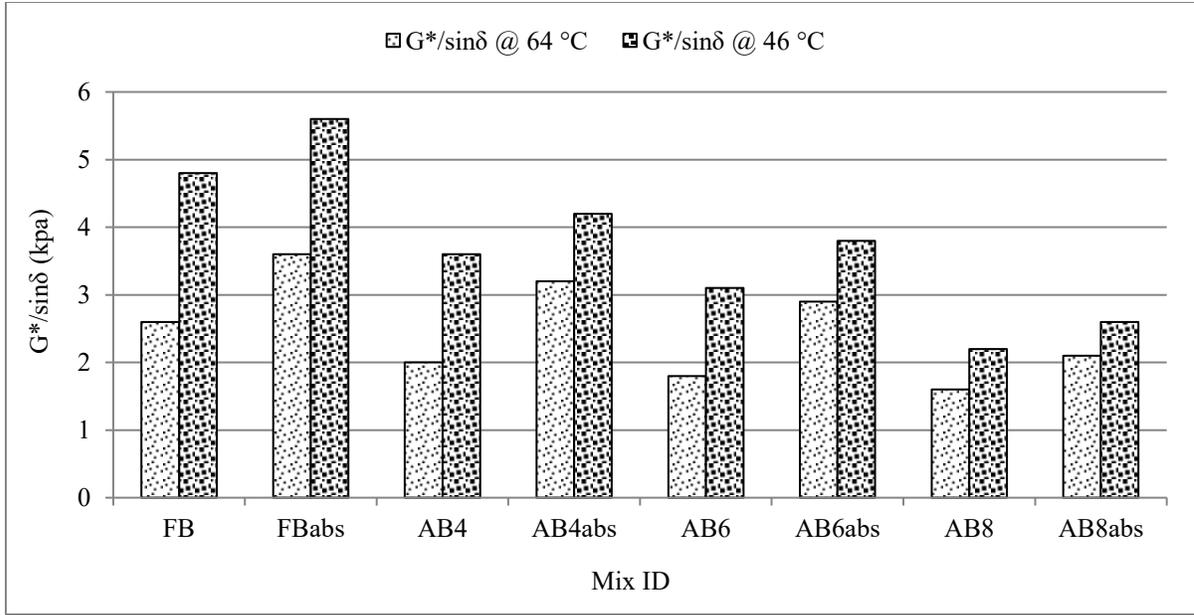


Fig. 10 variation  $G^*/\sin\delta$  for different asphalt specimens

### 6. Mechanical Properties

Fatigue and rutting are important mechanical properties of asphalt mix in designing and maintaining asphalt pavements. Flexible pavement failures and life span can be prevented or delayed by using high-quality materials or modified bitumen in the bituminous mix. Fatigue life and rutting resistance of Semi-Dense Bituminous Concrete (SDBC) mix, conforming to IRC-95, containing different asphalt specimens considered in this research, shown in Table 1, were determined. In order to assess the mechanical properties of various asphalt specimens, the fatigue life was determined using a pentrometer four-point bending beam test, which conformed to the standard AASHTO T321 (2017) at  $100\mu$ -strains and  $20^\circ\text{C}$ . Rutting resistance was determined using Hamburg wheel tracking, which conformed to

AASHTO T324 (2015) at  $60^\circ\text{C}$  for 5000 cycles for two different frequencies, 2Hz and 5Hz. [42, 43]. Figures 11 show that the asphalt mix containing ABS-modified asphalt has a higher fatigue life than conventional asphalt of all ages. This can be attributed to a number of factors, including the asphalt binder’s increased viscosity, the asphalt’s improved adhesion to aggregate particles, and the asphalt’s ability to act as a water barrier. [44, 45]. Figure 12 shows that the rutting resistance is reduced at lower frequencies of 2 Hz than at higher frequencies of 5 Hz loading. This is because lower frequencies of loading allow the asphalt binder to recover from deformation during the application of a load more readily, whereas higher frequencies of loading give the asphalt binder less time to recover from deformation before the next load is applied. [46, 47].

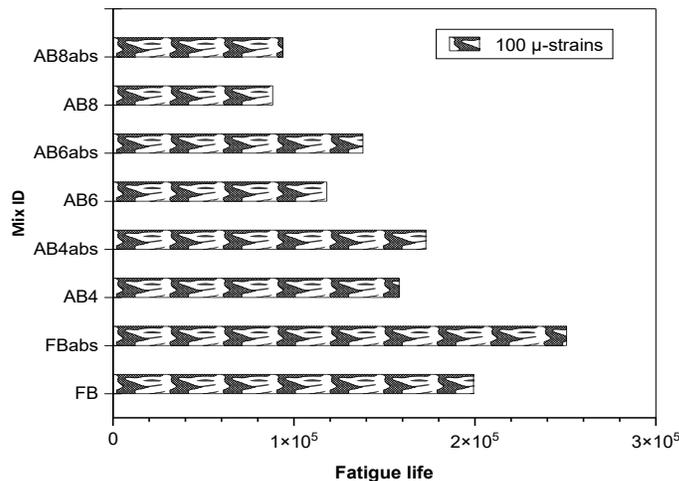


Fig. 11 Variation of fatigue life

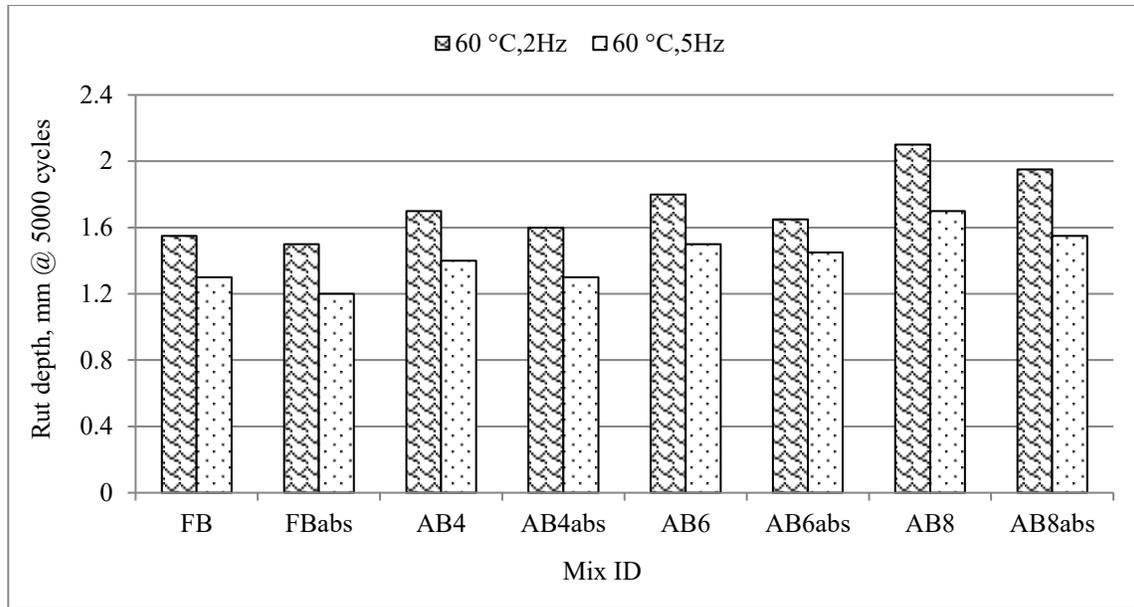


Fig. 12 Variation of rutting for different mixes

## 7. Conclusion

In these studies, the mechanical, rheological, and physical characteristics of both new bitumen and 2, 4, 6, and 8 years old recovered asphalt-with and without ABS-are assessed and contrasted. The improved quality of recovered asphalt for reuse is greatly influenced by the ABS. The conclusions that were reached are listed below;

- The physical structure of the asphalt was changed with the inclusion of ABS as a partial replacement. The new peaks were observed in the results obtained from the fluorescent microscopic examination. The better peaks were observed in the new virgin bitumen contained with ABS than in the aged bitumen combined with the ABS.
- The rheological parameters of the asphalt mix containing ABS as a partial replacement were found to have improved penetration value, viscosity, complex shear, and rutting parameter ( $G^*/\sin\alpha$ ), which are enhanced.
- While comparing the fresh bitumen with and without ABS, the fresh bitumen with ABS showed enhanced physical and rheological properties, such as fatigue life and rutting resistance.

- The asphalt mix with virgin mix improved in their mechanical and viscoelastic properties without affecting the required volumetric properties. Hence, it is recommended to add ABS to the virgin Asphalt mix.

Based on the results, it was determined that recycled bitumen that has been treated with ABS may be utilised in pavement construction to partially replace virgin bitumen.

## Future Scope of this Research

This research was done only for the SDBC Mix, which performed well in the field conditions. Hence, this research can be extended to the other asphalt mixes specified in MORTH and IRC specifications.

## Limitations of this Research

In this research, asphalt specimens are not tested in extreme temperatures, such as zero-degree temperature and at higher temperatures, and no field studies are done to ensure the use of ABS in the asphalt Mix.

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