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Mechanical properties of asphalt mixtures containing reclaimed asphalt incorporating Acrylonitrile Butadiene Styrene (ABS)

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ABSTRACT

Huge accumulations of Recycled asphalt pavement (RAP), scarcity of bitumen obtained from natural resources, RAP causing environmental pollution, and increased construction of flexible pavement all over the world led the researchers to reuse the improved aged bitumen by modifiers. Hence, in this research, the reclaimed aged asphalt improved by ABS (5% weight of virgin bitumen) was partially replaced by virgin bitumen (10 to 60% with an increment of 10%) used in the asphalt mix, and mechanical properties such as stability, flow, rutting resistance, fatigue life, Indirect Tensile strength, and resilient modulus were investigated. The research concluded that the aged reclaimed asphalt containing 5% ABS can be partially replaced up to 30% by conventional virgin bitumen, exhibiting better performance without compromising the mechanical properties of the asphalt mix.

Keywords: Asphalt mix; Reclaimed Asphalt; Waste; Fatigue; Rutting.

1. INTRODUCTION

With more than 600 million kilometers of roads, China has the longest road infrastructure in the world with over 4.5 million km followed by India, which has an additional 5.4 million kilometers [1]. Around 90% of India's roads are built with flexible pavement, and the entire road network has an overall length of 54.83 lakh km. In India, around 90% of the roads are built with flexible pavement, and the total length of the road network is 54.83 km [2]. Road construction uses a significant amount of natural resources, such as aggregates such as gravel, sand, and crushed stone, to construct the base, sub-base, and surface courses of roads. Bitumen, which is a sticky, black tar-like substance that is used to bind, aggregates together in asphalt, Sustainable road construction is an important way to reduce the environmental impact of roads. By using recycled materials, improving efficiency, and using sustainable materials, we can build roads that are better for the environment [3].

An industrial waste could easily be incorporated into pavement design to preserve pavement quality [4]. Guidelines for the use of waste materials, such as blast furnace slag, steel slag, and copper slag, for the inclusion of different pavement layers in road constructions built in rural areas have been issued by the INDIAN ROAD CONGRESS [5]. The recycle materials are possible to use as the partial replacement in the virgin asphalt mix which does not affect the Marshall parameters such as volumetric parameters, stability and flow in the construction of the new flexible pavement [6]. The study's findings reveal that the approach of establishing hot recycled asphalt mixtures with the incorporation of RAP is not only an appealing choice based on the notion of environmental sustainability, but also a source of financial expense reduction relying on rivalry for the design of flexible asphalt pavement overlays [7]. The researchers also found out that, the virgin binder consumption can be reduced by 12.9% and 35.7% by incorporating 10% and 30% RAP respectively in the virgin asphalt mix [8].

Plastics became a widespread commodity; they penetrate every aspect of human life today. In 2015, the production of plastics increased from 2 000 tons in 1950 to 322 000 tons [9]. In order to reduce the construction cost and disposal in landfills that cause environmental problems, the aged bitumen and aggregate obtained from the Recycled Asphalt pavement (RAP) material have to be reused [10, 11]. Hence, the researchers are focused on restoring the aged reclaimed bitumen property closer to the virgin bitumen to reuse the bitumen in flexible pavement construction [12].

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The modification of bitumen binder is typically done using thermoplastic polymer materials such as Thermoplastic Polymers, Thermosetting Plastics, rubbers, and Block Copolymers, with the aim of improving the performance of bitumen by increasing its viscosity and rutting sensitivity [13, 14]. The elastic and viscous properties of bitumen get improved to a greater extent at 5% replacement of Acrylonitrile Butadiene Styrene (ABS) by virgin bitumen [15]. Abs containing bitumen are stiffer at low temperatures and have high resistance to higher temperatures [16]. Hence, this research focuses on the reuse of aged bitumen as a partial replacement for virgin bitumen by adding ABS as a modifier to the reclaimed asphalt.

2. MATERIALS USED

2.1. Virgin bitumen and aggregate

The bitumen grade VG30, based on the viscosity grade classification used according to IRC 37-2018, is recommended for semi dense bituminous concrete (SDBC) used for the construction of expressways and national highways whose design traffic is less than or equal to 20 million standard axles. The physical characteristics of the VG30 bitumen confirm IS73-2006, which was used in this research. The Physical characteristics of VG30 bitumen obtained through laboratory tests are shown in Table 1. Locally available natural broken stones in different fractions were obtained from a nearby quarry in Tamil Nadu, India. The different fractions used are coarse aggregate greater than 2.8 mm size, fine aggregate (2.8 mm to 90 µm) and filler material size less than 90 µm and a maximum size of 13.2 mm aggregate for SDBC mix, with physical characteristics confirming the IRC95-1987 used. Figure 1 shows the particle size distribution of aggregate grading II required for SDBC mix used in this research.

Table 1: The physical characteristics of VG30 bitumen (virgin).

SL. NO.	PHYSICAL CHARACTERISTICS	LABORATORY VALUE	RECOMMENDED VALUE	REFERENCE
1	Absolute viscosity, poises at 60 degree centigrade	2563	Minimum 2400	IS 1206-2
2	Kinematic viscosity, centistokes at 135 degree centigrade	395	Minimum 350	IS 1206-3
3	Penetration value at 25 degree centigrade	62	50-70	IS 1203
3	Softening point using ring and ball apparatus, degree centigrade	54	Minimum 47	IS 1205
4	Flash point using cleveland open cup, degree centigrade	235	Minimum 220	IS 1209
5	Ductility after thin film oven test at 5 degree centigrade, mm	48	Minimum 40	IS 1208

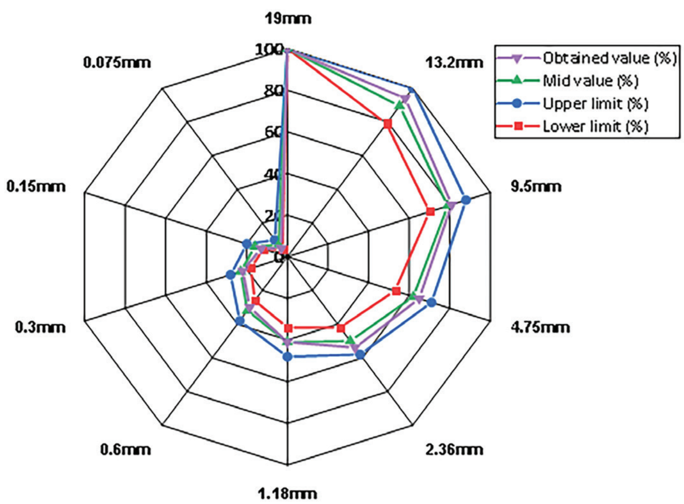

Figure 1: Particle size distribution of aggregate used in SDBC mix.

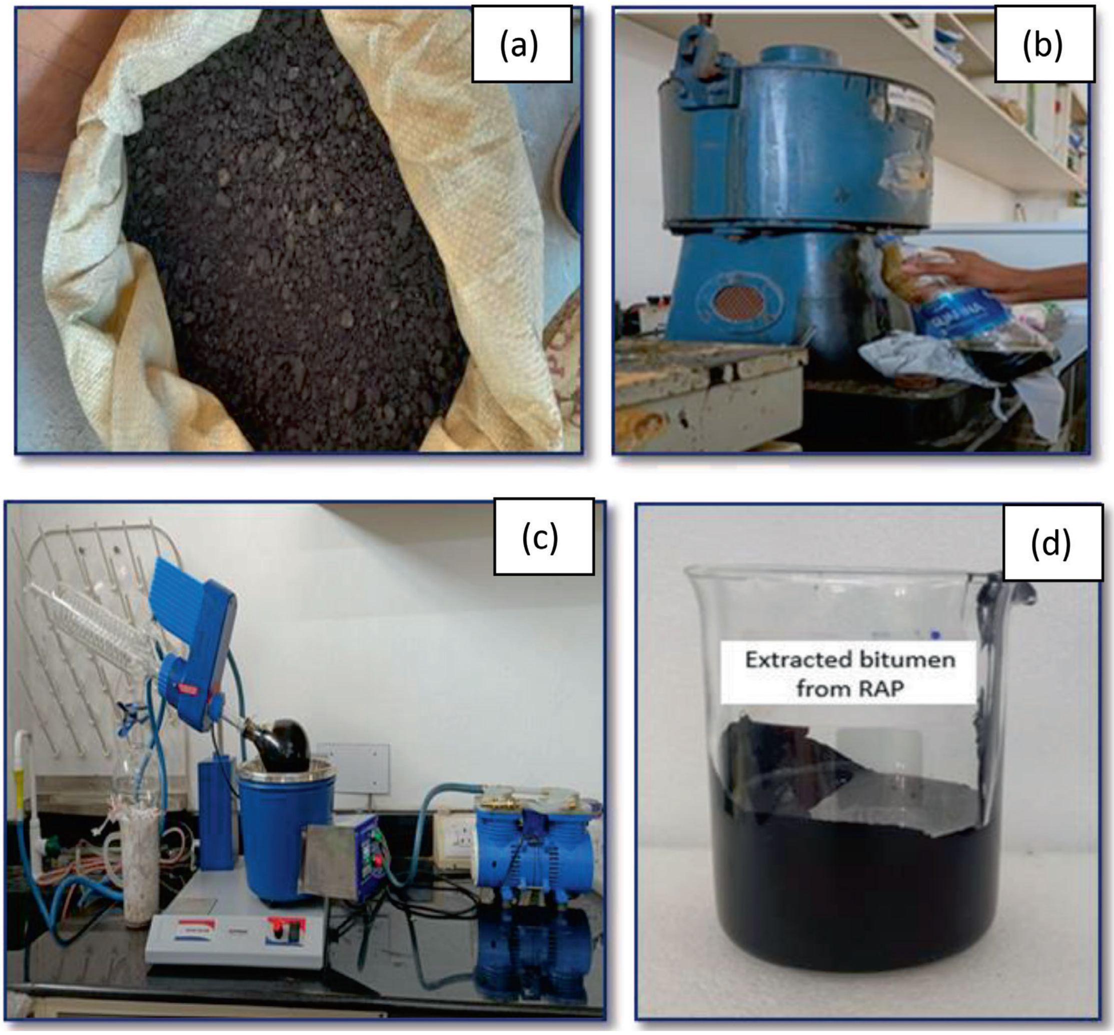

Figure 2: Materials used for the experimental work (a) RAP material (b) bitumen along with trichloroethylene (c) vacuum bitumen extractor (d) extracted bitumen.

2.2. Recycled bitumen

The five-year-old reclaimed asphalt pavement (RAP) material is collected from the source and broken into finer pieces as shown in Figure 2(a) for the extraction of aged bitumen. The bitumen along with trichloroethylene were obtained from the RAP in solution form, as shown in Figure 2(b), by following the test procedure and confirming the standard IRC: SP11-1988 and ASTM D-2172. The bitumen alone was extracted from the mixture of bitumen and trichloroethylene by the principle of a rotary vacuum evaporator, confirming the standard ASTM D5404-97. Figure 2(c) shows the experimental set-up. In this procedure, the sample containing the mixture of bitumen and trichloroethylene is taken in the round-bottom flask fitted to the apparatus. The temperature of the water bath was set and filled with freshly distilled water. The vacuum pump was turned on to generate vacuum in the system. The flask rotates at a speed of 270 rpm. Both inflow and outflow of water are ensured until the test is complete. The revolving flask continues to revolve at a standard temperature. Condensed solvent is collected in the receiving flask after it has evaporated, and the extracted bitumen is collected as shown in Figure 2(d).

2.3. Modified recycled bitumen

Acrylonitrile Butadiene Styrene (ABS) obtained from the electronic waste used in this research is shown in Figure 3. ABS is one of the different types of e-waste available on the market and consists of rubber and styrene acrylonitrile [17]. The recycled bitumen obtained by mixing reclaimed asphalt with 5% ABS using the shear mixer shown in Figure 3(a) rotates at a speed of 2700 rpm for duration of 30 minutes. In the dispersion of reclaimed asphalt using a fluorescence microscope, shown in Figure 3(b), the asphalt-rich phase appears dark, whereas the polymer-rich (ABS) phase appears light, as shown in Figures 3(c) and 3(d).

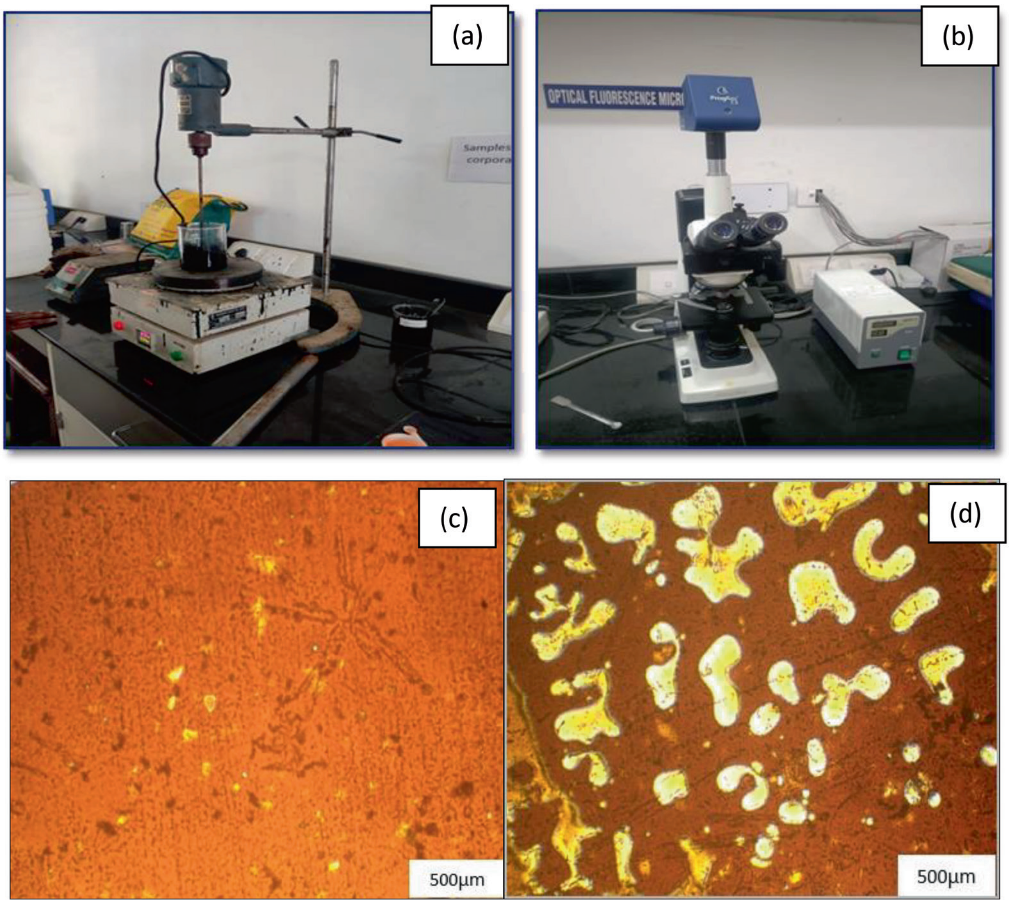

Figure 3: Various examinations of the materials (a) shear mixer (b) optical fluorescence microscope (c) reclaimed asphalt (d) ABS modified reclaimed asphalt.

Table 2: Asphalt mix designations.

SL. NO.	ASPHALT MIX ID	OPTIMUM BITUMEN CONTENT BY WEIGHT OF MIX (%)	VIRGIN ASPHALT (%)	RECLAIMED ASPHALT CONTAINED 5% ABS (%)	REMARKS
1	M100-0	5.84	100	0	Reference asphalt mix with 100% virgin bitumen
2	M90-10	5.79	90	10	Asphalt mix with virgin bitumen and reclaimed asphalt with 5% ABS
3	M80-20	5.73	80	20	
4	M70-30	5.69	70	30	
5	M60-40	5.63	60	40	
6	M50-50	5.59	50	50	
7	M40-60	5.58	40	60	

2.4. Asphalt mix designation

The details of the asphalt mix proportions considered for the experimental program are given in Table 2. The specimens designated as M100-0, M90-10, M80-20, M70-30, M60-40, M50-50, and M40-60 contained an ABS percentage. The specimens with the letters M100-0 represent the reference asphalt mix with 100 percent virgin bitumen and zero percent reclaimed asphalt with ABS. Ex.: M60-40 represents the asphalt specimen containing 60 percent virgin bitumen and 40 percent reclaimed asphalt with ABS.

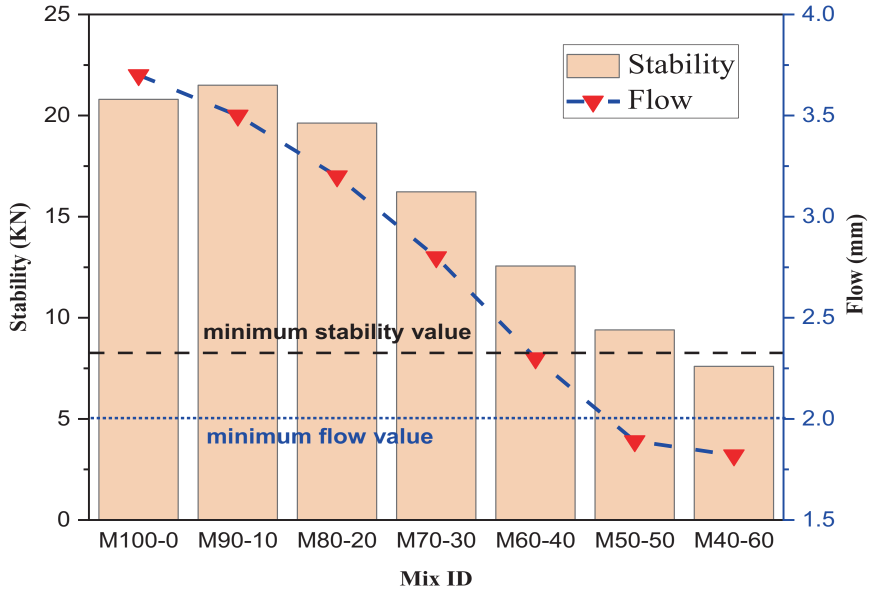

Figure 4: Marshall stability and flow.

3. RESULTS AND DISCUSSION

3.1. Marshall stability and flow

The Marshall Stability and flow test was conducted according to the standards AASHTO T-245 (AASHTO, 2015), ASTM D 1559, and IRC 111. The specimen's diameter and height are approximately 100 mm and 63.5 mm. The specimen testing temperature was kept at 60 °C 10 °C, and the loading rate was kept at 0.5 cm/minute. The maximum load sustained by Marshall Specimen before failure, called stability and flexibility or flow, is the change in diameter of the specimen between the start and maximum load sustained along the direction of loading on Marshall Specimen. The optimum binder content satisfying the mechanical properties and volumetric properties for SDBC (semi-dense bituminous concrete) mixes according to IRC-95 is given in Table 1. According to IRC-95, the minimum stability required is 8.2 KN, and the flow value falls within the range of 2–4 mm. From Figure 4, for all asphalt mixes except M40-60, the stability value is higher than the minimum requirement of 8.2 KN. The increased stability of M90-10 may be due to the inclusion of ABS polymers, which act as bridges between the asphalt molecules, forming a network that helps prevent the asphalt from flowing or segregating. This is because polymers have long, flexible chains that can entangle with the asphalt molecules, creating a strong network [18]. From Figure 4, for all asphalt mixes excluding M50-50 and M40-60, the flow value falls below the minimum requirement. For all the asphalt mixes, the flow value obtained decreases with the inclusion of ABS-modified reclaimed binder because ABS polymers act as a stiffening agent [19]. They do this by forming cross-links between the asphalt molecules, which makes the asphalt more rigid and less susceptible to flow. This is beneficial for asphalt mixes because it makes them highly resistant to rutting and other forms of deformation [20].

3.2. Indirect tensile strength and moisture sensitivity

An indirect tensile strength test confirming standards EN 12697-23 and ASTM D6931-12 was performed. From Figure 5, it was observed that indirect tensile strength increased for mix M90-10 when compared to the reference mix M100-0, and for the remaining mix, ITS got reduced, while the indirect tensile strength ratio was higher than the desirable ITS ratio of 0.8 [21]. The indirect tensile strength of asphalt mixes decreases with the inclusion of polymers contained in asphalt, possibly because the polymers act as plasticizers [22]. The intermolecular forces between the asphalt molecules make the asphalt more pliable and less susceptible to fracture [23, 24]. The presence of polymer in reclaimed asphalt improves the adhesion between the asphalt and the aggregate, making the asphalt mix more resistant to cracking, which increases the ITS ratio and moisture resistance [25, 26]. The polymers improve the adhesion between the asphalt and the aggregate, making it more difficult for water to penetrate the mix and weakening the bond between the asphalt and the aggregate, making it less susceptible to moisture damage [27].

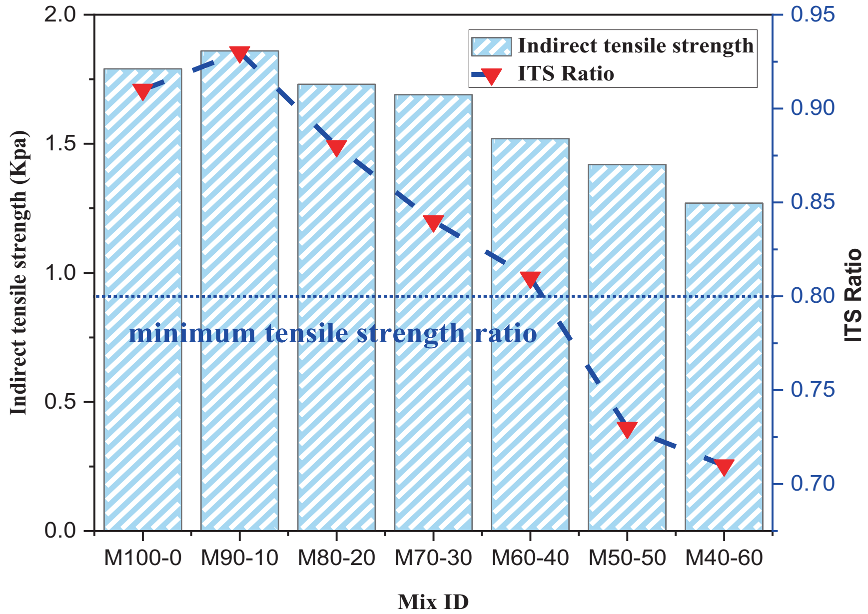

Figure 5: The indirect tensile strength and ITS ratio.

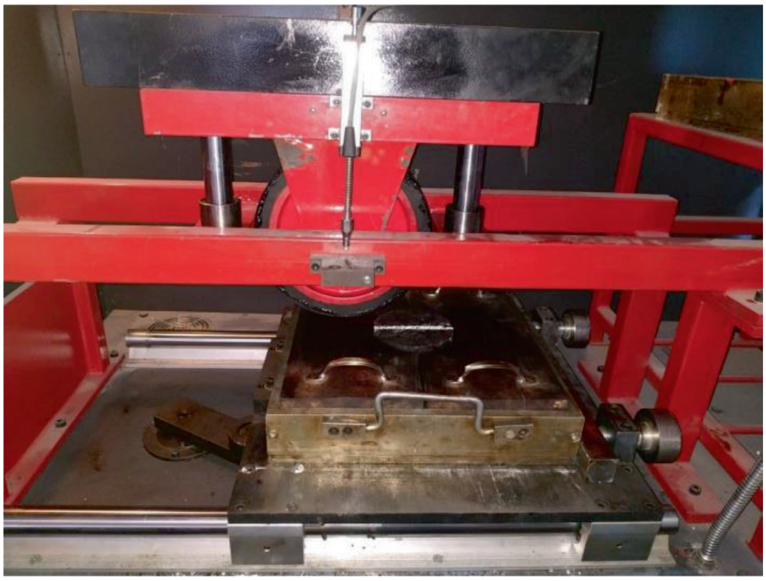

Figure 6: Hamburg wheel-track testing set-up.

3.3. Rutting

Rutting testing is also called Hamburg wheel-track testing. The test was conducted, confirming standards AASHTO T 324 and EN 12697-22. This experiment was used to evaluate the asphalt mix's resistance to permanent deformation along the loading wheel path [28]. The rectangular size of the specimen was 300 mm × 300 mm, and the thickness was 50 mm in this experiment. The temperature maintained throughout the test was 60 °C. The test setup is shown in Figure 6. The rut depth was measured at the following passes: 2000, 4000, 6000, 8000, 10000, 12000, 14000, and 16000. Figure 7 shows that rutting resistance has a lower and more linear relation at lower cycles up to 8000 cycles for all the mixes; beyond that, rutting resistance increases with increasing cycles due to the aggregate particles in the asphalt mix becoming more compacted because load cycles help break down the air voids in the mix, which leads to aggregate getting tightly packed together [29], and the polymer chains in the asphalt mix becoming more aligned with increasing load cycles due to the orientation of the polymer chains in the same direction, both making the asphalt mix more resistant to deformation [30]. Overall, the asphalt mix M90-10 has higher rutting when compared to all other asphalt mixes.

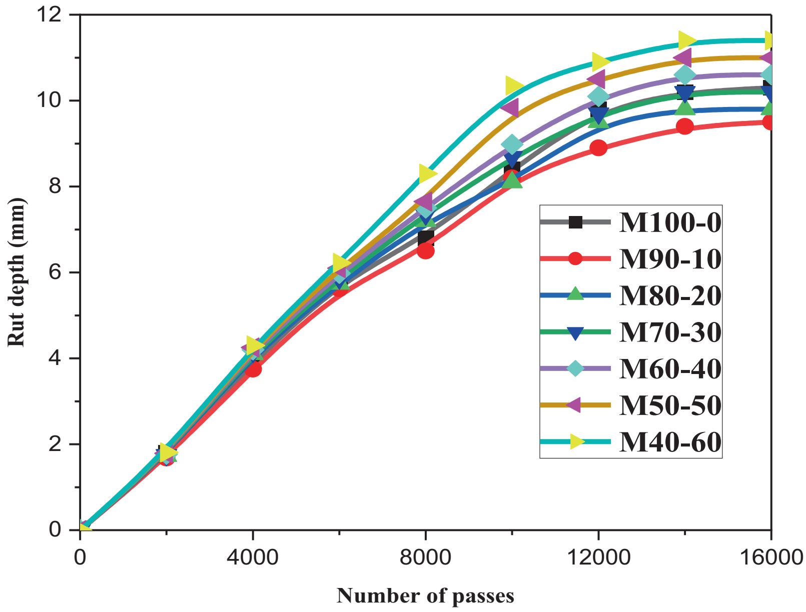

Figure 7. The rutting resistance at 60˚C.

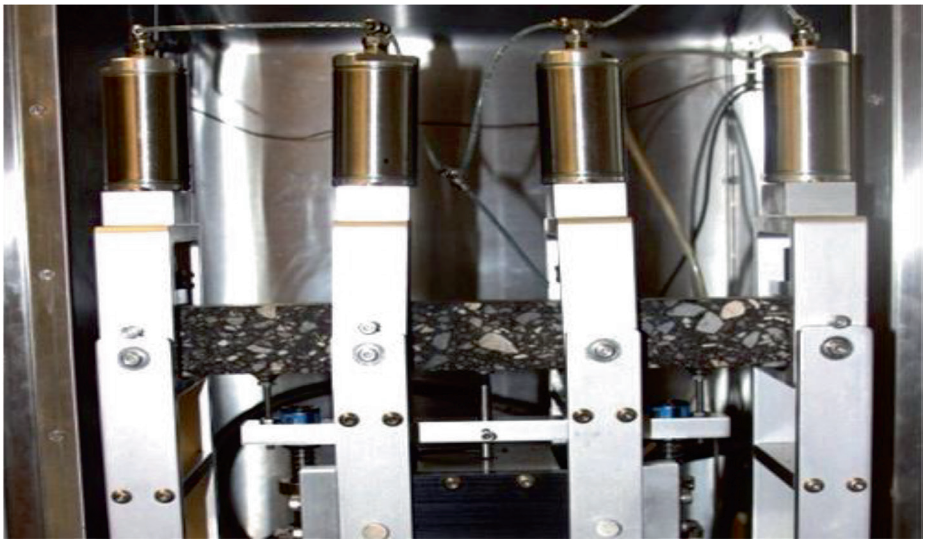

Figure 8: Four point bending fatigue test set-up.

3.4. Fatigue life

The fatigue test was conducted according to Standard AASHTO T 321 [31]. This experiment was used to evaluate the fatigue life of asphalt mix. A rectangular beam specimen of size 381 mm × 51 mm × 63.5 mm was used in this experiment. The temperature maintained throughout the test was 20 °C, and a sinusoidal load was applied to the specimen, maintaining a frequency of 10 Hz. The fatigue life was determined for 200 µ strains, 400 µ- strains, 600 µ- strains, and 800 µ- strains. The test setup is shown in Figure 8. Figure 9 shows that at a lower strain rate, the fatigue life observed is higher due to the asphalt mix having more time to recover, relax, and return to its original shape between loading cycles. This allows the asphalt mix to dissipate the energy from the loading cycles and prevents the accumulation of damage. At a higher strain rate, the asphalt mix does not have enough time to recover from the elastic deformation before the next load cycle is applied, leading to more plastic deformation and thus a shorter fatigue life [32–34]. However, the asphalt mix M90-10 was found to be optimal. The polymers in asphalt mixes help to prevent fatigue cracking by increasing the stiffness of the mix, making it less likely to form cracks [35]. In addition, the polymers in the asphalt mix improve the adhesion between the asphalt and the aggregate, making it difficult for cracks to propagate through the asphalt mix [36].

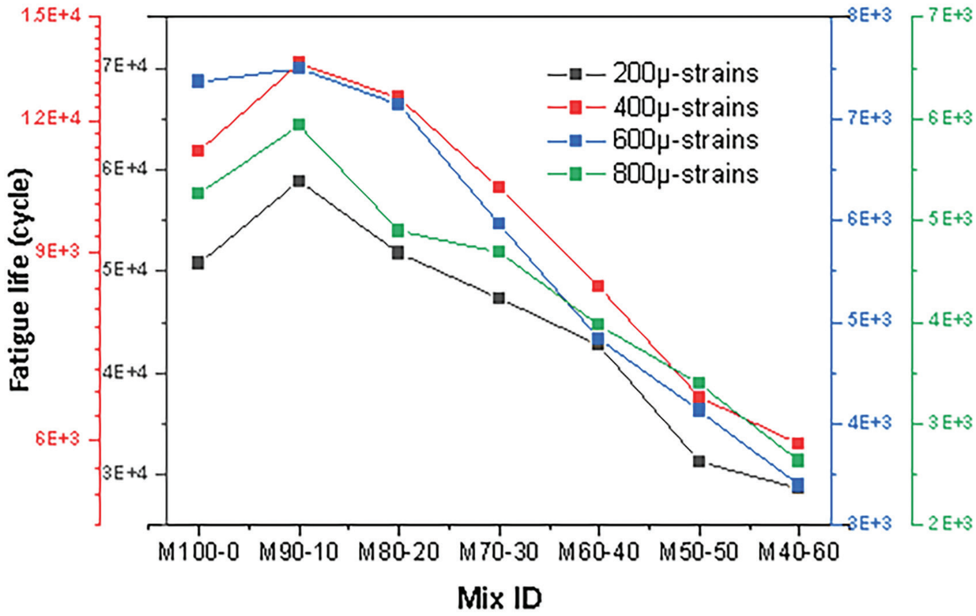

Figure 9: The fatigue strength of the specimens.

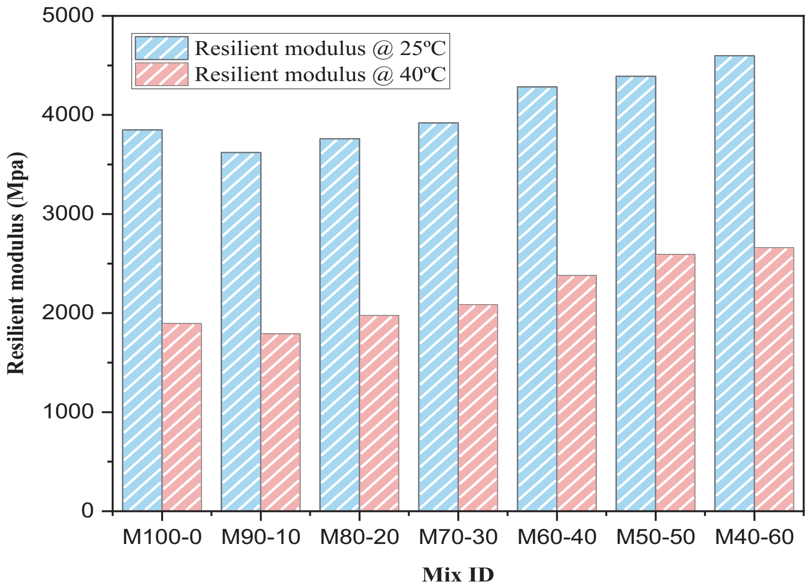

Figure 10: Resilient modulus at 25˚C and 40˚C.

3.5. Resilient modulus

Resilient Modulus was conducted, confirming the standard with ASTM D7369. It's a function of recoverable deformation along the horizontal direction and the Poisson ratio of the asphalt specimen, which is resistance to deformation against load. The resilient modulus obtained for the two different temperatures of 25 °C and 40 °C Figure 10 shows that, at lower temperatures, asphalt has a higher resilient modulus due to the fact that its molecules are tightly packed and are resistant to flow and deformation [37, 38]. At higher temperatures, the lower resilient modulus of asphalt is able to absorb less energy because asphalt becomes more viscous and aggregate also gets loosely packed [39, 40]. The inclusion of polymer-containing reclaimed asphalt improved the resilient modulus of mixes M90-10, M80-20, and M70-30 when compared to reference mix M100-0 for both temperatures of 25 °C and 40 °C, respectively. The presence of polymer makes the asphalt mix stiff, deformable, and reduces the energy absorbed by aggregate [41–43].

4. CONCLUSION

The asphalt mix comprise of ABS with partial replacement RAP found to have has a significant impact on improving the reclaimed asphalt for reuse. From the results obtained from this research it was found out that, the Marshall Parameters falls within the limit up to 40% replacement of virgin bitumen by reclaimed asphalt with ABS. The performance parameters such as Indirect tensile strength, fatigue life and rutting resistance get improved up to 30% partial replacement of RAP with virgin asphalt mix with 5% ABS except the resilient modulus found to be satisfactory up to 40% replacement of RAP for both the test temperature of 25 °C and 40 °C considered in this research. Overall results obtained from this research show that virgin asphalt mix can be replaced by reclaimed asphalt with 5% ABS up to 30% without compromising the volumetric and mechanical properties of asphalt mix does not affect the performance of the asphalt mix.

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