Laboratory Performance Evaluation of Copper Slag in Semi-dense Bituminous Concrete

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Evaluation of properties of fibre reinforced asphalt mix with copper slag as the filler

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ABSTRACT

Rapid economic growth of countries requires continued expansion of the road network, which requires a huge volume of natural resources. Broken stones of coarse and finer sizes cause depletion of natural resources. On the Other hand, disposal of industrial waste is a great challenge. Hence, this research, the conventional filler (quarry dust) completely replaced by copper slag and glass fibre included in the asphalt mix varying from 0.1% to 0.4% by volume of asphalt mix with na incremente of 0.1%. The volumetric and mechanical properties investigated in the laboratory. The experimente results concluded that the asphalt mix with copper slag as filler and the fiber length of 8 mm with 0.2% by volume of mix exhibited optimum performance without compromising the volumetric properties.

Keywords: Fibre; Copper Slag; Fatigue; asphalt mix; Indirect tensile strength (ITS).

1. INTRODUCTION

In India, 90% of the roads are constructed with flexible pavement, and the total road network covers a total length of 54.83 lakh kilometers [1]. The incorporation of wastes such as roofing shingle wastes, glass, flyash, municipal solid waste combustion ash, rubber tires, carpet fiber, by-products of coal ash, blast furnace slag, and steel slag, and recycled plastic are available in huge quantities from industry for Highway construction, reducing the use of conventional natural resources and disposing of constraints [2]. Industrial waste was easy to incorporate in pavement construction to maintain good quality [3]. The construction and lifecycle costs were found to be less When compared to the conventional asphalt mixes used in road construction [4]. The Indian Road Congress (IRC) has given guidelines for the use of waste materials such as blast furnace slag, steel slag, and copper slag for in corporation on different pavement layers both in flexible and rigid pavement construction constructed in rural areas [5]. Copper slag is one of the huge industrial wastes produced by the copper industry. In the global market, Chile ranked number one in copper production with a share of 30% of total global copper production, with 80% of the economic activity depending on the generation of copper raw material [6]. Nearly 2.2 to 3.0 tons of copper slag are generated for every one-tone production of copper, leading to the generation of 4.5 million tons of copper slag very year; as of now, a total of 50 million tons of copper slag have been accumulated [7, 8]. Every year, nearly 6,000 metric tons (MT) of copperslag are produced in Tamil Nadu, India, by Sterlite Industries. As a result, there searchers believe that the only scientific solution to safe disposal is to reuse the quantity of copper slag that is accumulated in the land fill [6, 9]. In chemical analysis, it was found that the copper slag has the following chemical composition: iron oxide: 30 to 40%, silicon oxide: 35 to 40%, aluminum oxide: 0 to 10%, and calcium oxide: 0 to 10% [6, 10]. The copper slag was categorized as non-hazardous material [11–13]. The asphalt mixes having 60% reclaimed asphalt pavement with 15% copper slag and 70% reclaimed asphalt pavement with 7.5% copper slag showed better performance without compromising on the following properties: resistance to rutting, fatigue life, dynamics tiffness, and moisture resistance [14]. The copper slag-contained asphalt mix has a high resistance to moisture and medium-to-long-term ageing [15]. The indirect tensile strength and resiliente modulus get increased for different temperatures (25 °C, 35 °C, 45 °C, 55 °C, and 60 °C) for the copper slag-contained asphalt mix when compared to the conventional asphalt mix [16]. From SEM analysis, it was found that there was no difference between the copper slag-incorporated asphalt mix and conventional asphalt mix [17]. Researchers changed the bitumen with polymers like chemical modifiers, crumb rubber, and natural rubber latex to improve the mix's fatigue life, aging, resistance to rutting, and

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resistance to water [18]. The use of fibers started in the 1950s. In the bituminous overlay, they used wiremesh as reinforcement to arrest the reflective cracking [19]. The use of fibers improves the strain energy absorbed when the asphalt mix is subjected to fatigue and fracture [20]. It was observed that there was improvement in the tensile strength of the asphalt mix with the inclusion of fibers [21]. The bituminous concrete incorporated with synthetic fibers has been investigated throughout the world by researchers to improve the mechanical Properties of the asphalt mix [22, 23].

The asphalt mix with 0.25% glass fiber content performed better without compromising the standard permissible values for the mechanical and volumetric properties of asphalt mix. The indirect tensile strength increased by 5% when compared to the conventional asphalt mix. The rutting resistance increased by 20% when compared to the conventional mix [24]. The fiber-contained asphalt mix had high resistance to high and low temperatures, and at the same time, it had high resistance to moisture sensitivity [25]. In the fiber-contained asphalt mix at a low temperature of –20 °C, it was found that there was an 80% increase in post-crack toughness in the mix [26]. Short fiber reduces the stress to the maximum extent, improving the viscoelastic and effective modulus of a fiber-contained asphalt mix [27]. The aramid-polyalphaolefin fibers in the asphalt mix with a dosage of 0.45 kg/m^3 showed na increase in dynamic modulus [28]. Performance of an aramid-polyalphaolefin fiber-reinforced bituminous mix under the very low temperature of –20 ºC in the laboratory. By performing rectangular and semi-circular bending tests with conventional bitumen of 50/70 grade and polymer-modified bitumen. Both the bitumen-containing asphalt mixes showed positive effects with the inclusion of fiber [29]. High fracture energy was observed in the asphalt mix with fiber when compared with the conventional asphalt mix; the same trend was noted on the stress factor also. On the other hand, the low reduced frequency observed on the dynamic modulus test for all three types of the mix, such as conventional asphalt mix, asphalt mix with fiber, and asphalt mix with the modified binder. The properties such as toughness and tensile strength get improved, which implies that the asphalt mix containing polyester fiber has high durability against fatigue loading [30]. The inclusion of polypropylene fiber in dense graded asphalt mix improved properties such as resistance to moisture sensitivity, resiliente and dynamic modulus, flow number, fatigue resistance, and fracture energy [31].

In the literature review, it was found that the industrial waste copper slag obtained from the copper industry has improved mechanical Properties such as fatigue life, indirect tensile strength, resistance to moisture sensitivity, rutting resistance, increased energy absorption capacity, and increased stiffness, all without compromising the volumetric properties required in the asphalt mix. Thus, the copper slag maybe substituting for the conventional natural aggregate utilized in bituminous mixes. The mechanical properties of bituminous mix improved with the addition of fibers such as steel fiber, synthetic fibers such as glass fiber, polypropylene fiber, carbon fiber, etc. The fiber acts as the bridge on the failure plane while underload. The following characteristics, such as post-cracking behavior, fatigue life, dynamic modulus, resilient modulus, rutting, Marshall stability, flow, toughness, tensile strength, energy absorption, etc., get improved without compromising there quired volumetric properties in the asphalt mix with fiber than in the conventional mix without fiber. Simultaneously, the life cycle cost decreased due to improved performance and lower maintenance costs. There were no research studies found out with the combination of fiber sand partial replacement of copper slag bituminous mixes. Hence, research on the addition of polypropylene fiber combined with copper slag in bituminous concrete mixes was proposed in this paper.

2. MATERIALS AND METHODS

2.1. Bitumen

When heated, the thermo-viscous substance known as bitumen transforms into a liquid state. This study made use of bitumen with a viscosity grade of 30, also known as VG 30, approved for usage on Indian roads [1]. The properties of bitumen used in this research are shown in Table 1.

2.2. Aggregate (broken stones)

Marshall specimens are prepared using shattered stones of average sizes (12 mm and 6 mm) from a quarry available nearby. In order to prepare a quality asphalt mix, the shattered stones are screened to eliminate harmful impurities that affect the efficiency of the asphalt blend. The physical properties of the shattered stones used in this research are shown in Table 2.

2.3. Copper slag (as partial replacement of dust)

Copper slag acquired for this study from Sterlite Industries, a copper-producing company based in the state of Tamil Nadu in India. Both of the slag's physical attributes are broken down in depth in Table 3. Figure 1(a) show the copper slag used in research.

Table 1: Physical properties of asphalt grade VG30.

SL. NO	TEST METHODS	TEST RESULT	REQUIREMENT AS PER IS 73-2013 [32]
1	Ductility	64 cm	
2	Absolute viscosity	3800 poise	greater than 2400 poises
3	Kinematic viscosity	415 centistoke	greater than 350 centistoke
4	Flash point test	268 ºC	greater than 220 ºC
5	Solubility test	100%	greater than 99%
6	Penetration test	62	50-70
7	Softening point test	62 ºC	greater than 47 ºC

Table 2: Physical properties of shattered stones utilized in asphalt mix.

SL. NO	PHYSICAL PROPERTIES	TEST RESULT
1	Water absorption	0.43 %
2	Shape and texture of aggregate	the irregular and rough surface
3	The specific gravity of 12.5 mm shattered stones	2.71
4	The specific gravity of 6 mm shattered stones	2.63
5	The specific gravity of quarry dust	2.73
6	Bulk density	1.43 (g/cc)
7	Impact resistance value	19%
8	Flakiness and Elongation value	32%

Table 3: The physical characteristics of copper slag.

SL. NO	PROPERTY	DESCRIPTION/VALUE
1	Particle shape and texture	Irregular, sharp edge and rough
2	Fineness modulus	3.52
3	Specific gravity	3.94
4	Percentage of voids	41.19%
5	The fineness of copper slag	128 m^2/kg
6	Internal friction angle	50° 15’
7	Hygroscopic water	0.10%
8	Bulk density	2.08 g/cc
9	Water absorption	0.29 to 0.41%

Table 4: Properties of glass fibre.

SL. NO	PROPERTIES OF FIBER	SPECIFICATION
1	Geometry	Rectangle
2	Length of fibre	12 mm
3	Width of fibre	0.8 mm
4	Density of fibre	2.51 g/cm^3
5	Melting point of fibre	Higher than 320 ºC

2.4. Fibre

The incorporation of fibres into bituminous mix boosts engineering parameters such as stiffness fatigue life and rutting (permanent deformation along the wheel path) and therefore, fiber-based bituminous mix has emerged as a feasible choice for the building of asphalt pavements. Figure 1(b) shows the glass fibre used in this research. The physical properties of the glass fibre tabulated in Table 4.

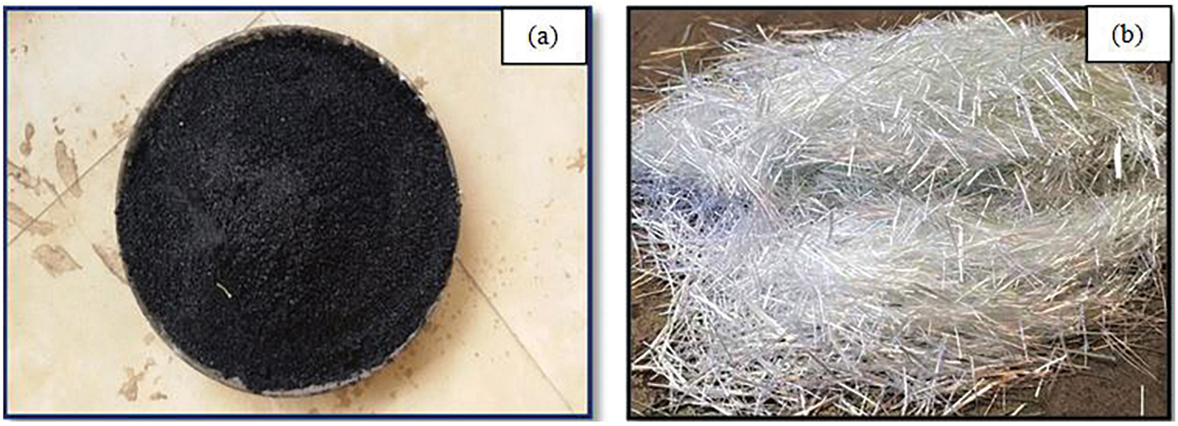

Figure 1: (a) The specimen of copper slag and (b) glass fiber.

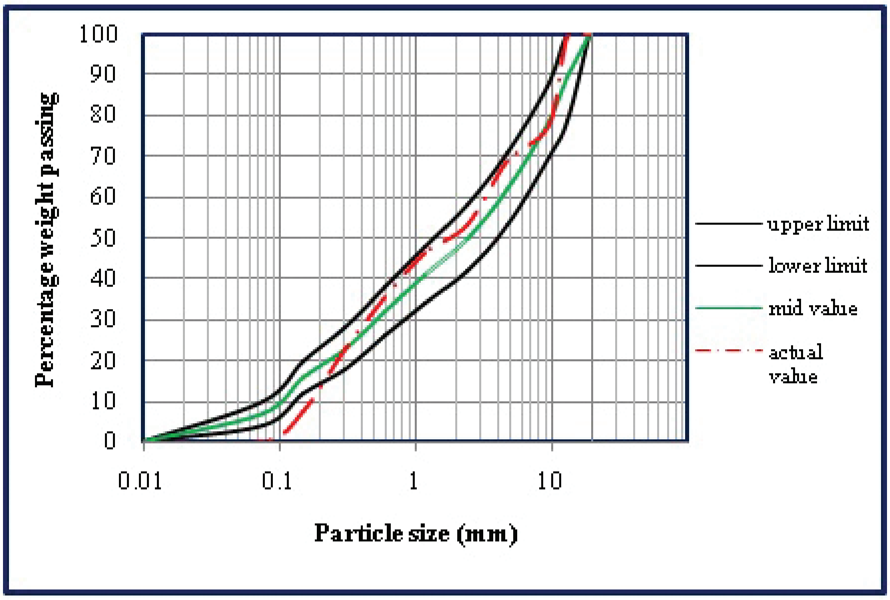

Figure 2: The combined gradation with conventional aggregate.

2.5. Aggregate combined gradation

The raw aggregate and copper slag collected from source not suitable for the preparation of asphalt mix (semi dense bituminous mix, grading 2 type (according to MoRTH [1]). In order to overcome this issue, it proposed in this research to segregate the aggregate and copper slag obtained from the source based on the size of the particles. The aggregates were grouped into particle sizes passing through sieve sizes such as 12.5 mm, 6 mm, 4.75 mm (quarry dust), and copper slag (size less than 4.75 mm). The segregated aggregates mixed at certain proportions to obtain aggregate particles that would be suitable for the preparation of asphalt mix.

For conventional combined aggregate gradation, aggregate sizes of 12.5 mm were retained at 10%, 6 mm at 30% and quary dust (size less than 4.75 mm) at 60% (by weight) retention on a specific sieve size were cumulated to prepare aggregate to satisfy the MoRTH (Ministry of Road Transport and Highways). The aggregate specification (semi dense bituminous mix, grading 2 type) for the preparation of the Marshall specimen shown in Figure 2. Similarly, for combined aggregate gradation with copper slag as filler. The aggregate size of 12.5 mm by 10%, 6mm by 30%, and copper slag (size less than 4.75 mm) by 60% (by weight), retained at a specific size, was utilized to produce the required graded aggregate, which satisfies the MoRTH (Ministry of Road Transport and Highways) [1] specification for the preparation of Marshall specimens, as shown in Figure 3.

2.6. Phase diagram of asphalt mix

Figure 4 depicts the schematic diagram of the asphalt mixture. When bitumen coated to the aggregate piece, aggregate used in asphalt mix absorbs part of the asphalt. The remaining bitumen forms a coating on the surface

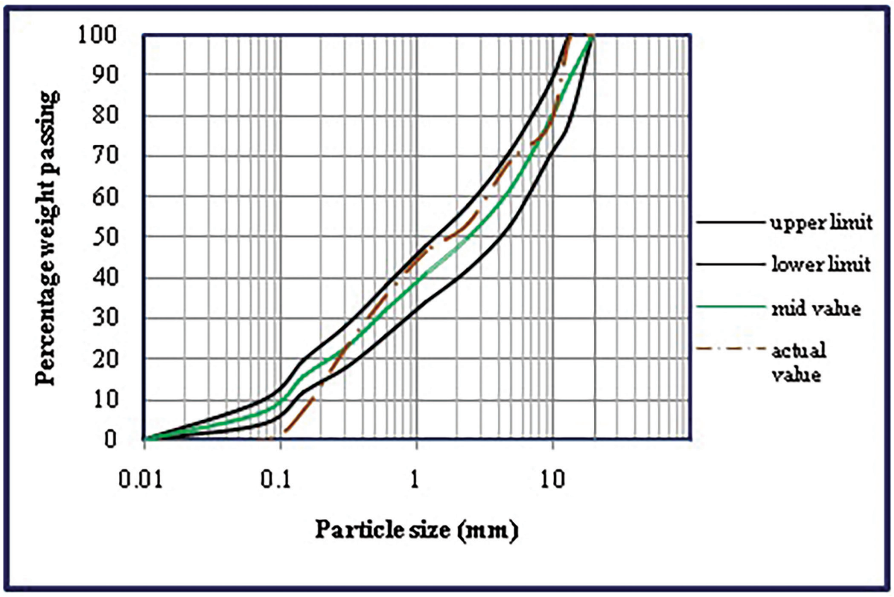

Figure 3: The combined gradations with copper slag as filler.

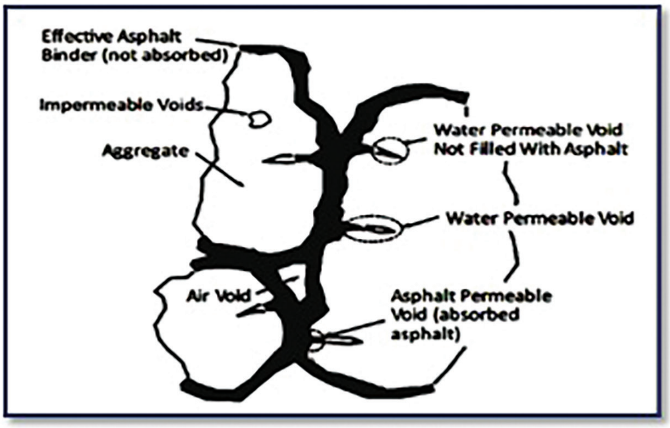

Figure 4: Microscopic view of the asphalt, crushed aggregate and air in the Marshall specimen.

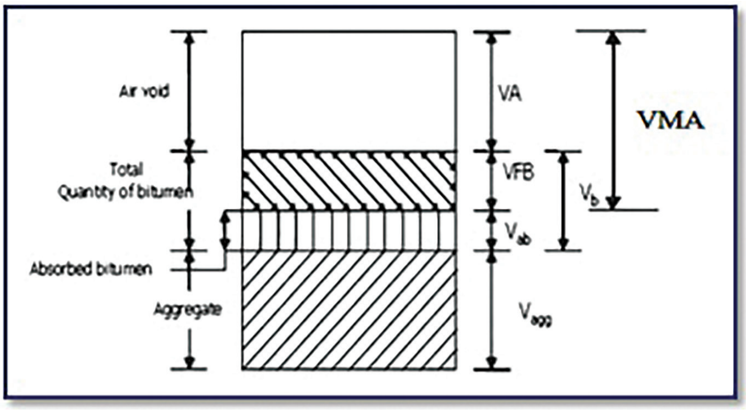

Figure 5: The phase diagram of the bituminous mix.

of the aggregate used in the asphalt mix. Air pockets occur within the asphalt mix, which is why the aggregate particles do not combine with the asphalt to create a solid mass. As illustrated in Figure 5, the four main constituents of hot mix asphalt are crushed aggregate, bitumen absorbed by the crushed aggregate, air, and bitumen that has not ingested into the crushed aggregate (useful bitumen).

Table 5: The range recommend in section 500 MoRTH for SDBC (Semi Dense Bituminous Mix).

SL. NO	PROPERTIES	RECOMMENDED VALUE
1	Air voids V_a	3 to 5%
2	Stability@ 60 ºC	≤ 8.2 KN
3	Flow Value	2 to 4 mm
4	V_{ma} (Voids in mineral aggregae)	13 to 17%
5	V_{fb} (Voids filed with bitumen)	65–75%
6	Compaction	specimen compacted by 75 blows in both sides

Table 6: The mix design and its types.

SL. NO	MIX ID	LENGTH OF FIBRE (mm)	DOSAGE %
1	MC0 (0 - 0)	-	0.00
2	M C60(0 - 0)	-	0.00
3	MC60(4 - 0.10)	4	0.10
4	MC60(4 - 0.20)	4	0.20
5	MC60(4 - 0.30)	4	0.30
6	MC60(4 - 0.40)	4	0.40
6	MC60(8 - 0.10)	8	0.10
7	MC60(8 - 0.20)	8	0.20
8	MC60(8 - 0.30)	8	0.30
9	MC60(8 - 0.40)	8	0.40
10	MC60(12 - 0.10)	12	0.10
11	MC60(12 - 0.20)	12	0.20
12	MC60(12 - 0.30)	12	0.30
13	MC60(12 - 0.40)	12	0.40
14	MC60(16 - 0.10)	16	0.10
15	MC60(16 - 0.20)	16	0.20
16	MC60(16 - 0.30)	16	0.30
17	MC60(16 - 0.40)	16	0.40

2.7. Asphalt mix references

The design parameters selected by MoRTH (Ministry of Road Transport and Highways) for the formulation of the mixtures are listed in Table 5. Different combinations of fiber lengths and doses used to prepare bituminous mixes for the control mix and the mix with partial substitution of conventional aggregate by copper slag. Seventeen mix designs listed in Table 6 done in laboratory. The mixtures labeled as MC (A-B), where M stands for mix, C represents the proportion of conventional aggregate replaced by copper slag, A represents the fiber length in millimeters, and B represents the fiber dosage by weight of aggregates. For instance, MC (0-0) represents the control mix with zero percent copper slag replacement, zero fiber length, and zero fiber dose. M60 (4-0.10) denotes 60% substitution of conventional aggregate with copper slag in a fiber-added bituminous mix with 4 mm of fiber length and 0.10% fiber dosage. The Marshall mix design procedure for control mix, the partial substitution of copper slag with conventional aggregate, and the glass fiber added asphalt blends with all feasible combinations of fiber dosages (0.1%, 0.2%, 0.3%, and 0.4% by weight of mix) and fiber lengths (4 mm, 8 mm, 12 mm, and 16 mm).

3. PERFORMANCE OF ASPHALT MIX WITH INCLUSION OF FIBRE AND COPPER SLAG AS FILLER

3.1. Volumetric properties

In the final phase of asphalt mix densification, there must be air pockets in the asphalt mixture. Nevertheless, the mixture would become flimsy because of excessive air pockets due to Young's modulus and fatigue life factors.

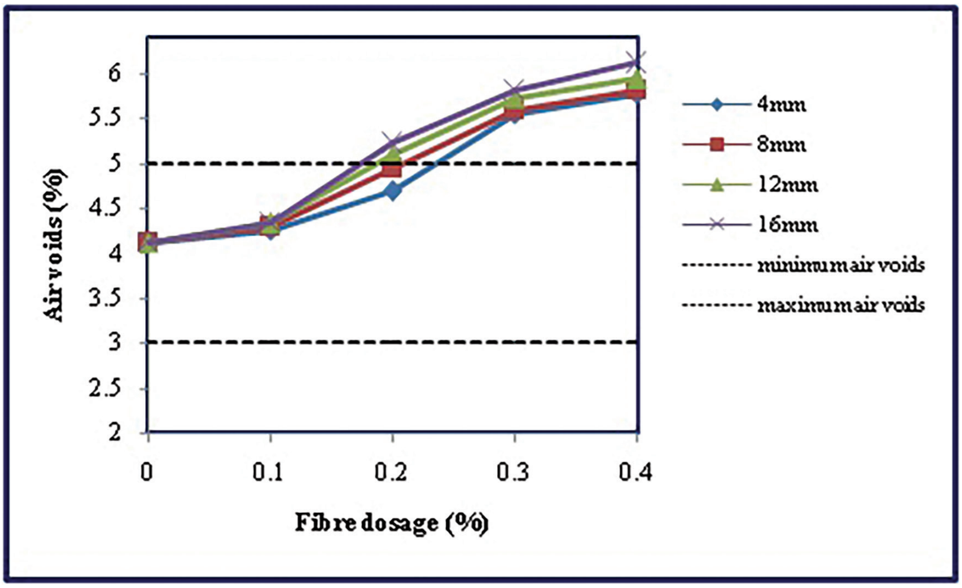

Figure 6: Comparison of air voids with various glass fiber doses and lengths in the SDBC Marshall specimen.

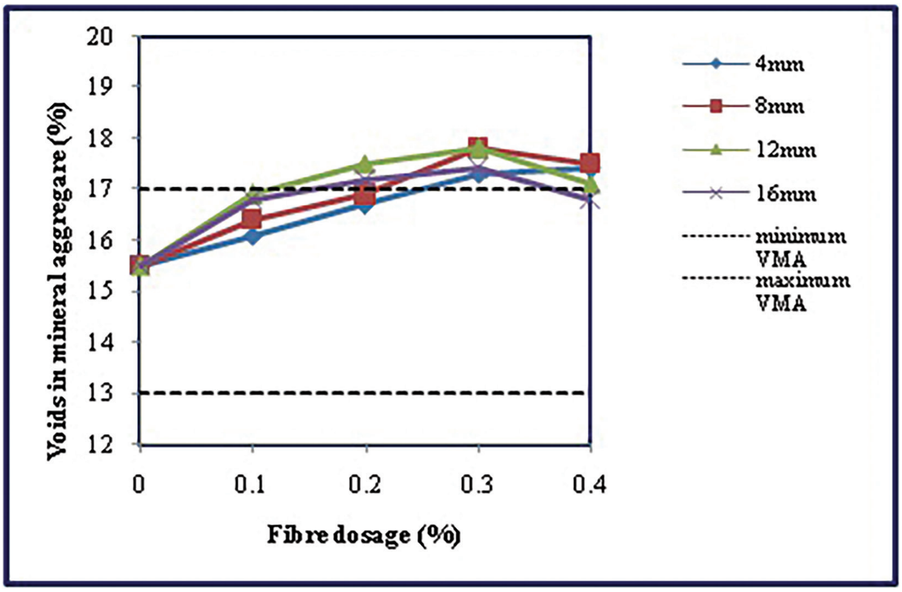

Figure 7: Comparison of Voids in Mineral Aggregate (VMA) with various glass fibre doses and lengths in the SDBC Marshall specimen.

The much more challenging and time-consuming process in the design mix process is evaluating and choosing the aggregate proportioning to achieve the desired thresholds for VMA (voids in mineral aggregate) and VFB (voids filled with bitumen). In order to obtain a long-lasting bitumen coating thickness, a minimal level of VMA must applied. A thin coating of asphalt on the asphalt mixture leads to low durability, which results from raising the density of the broken stones until they fall below the lowest VMA values procured.

The quantity of air void spaces in the bituminous mix affects how long the asphalt pavement will survive. This is because the air holes in the bituminous mixture are much smaller, making it much less porous. When there are too many air holes, corrosive air and water can get into the mixture. On the other hand, a low concentration of air-voids can cause blockage, which is when extra bitumen leaks through the asphalt mix and lands on the pavement surface. Air content and density are intimately associated. The proportion of void spaces inside the asphalt mix decreases as density increases, and vice versa.

According to Section 500 in MoRTH for SDBC (semi-dense bituminous mix), the recommended lowest air voids are 3 percent and the highest air voids are 5 percent to achieve a quality asphalt mix for better performance. From Figures 6 and 7, it can be observed that for the fibre lengths of 4 mm and 8 mm up to 0.2% fiber

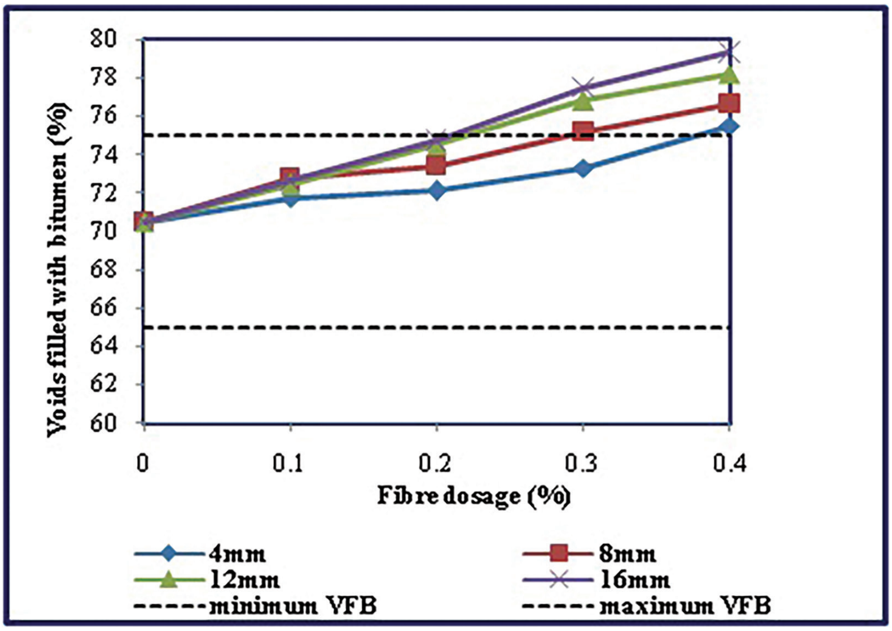

Figure 8: Comparison of Voids Filled with Bitumen (VMB) with various glass fibre doses and lengths in the SDBC Marshall specimen.

by weight of mix, the air voids (Va) and voids in mineral aggregate (VMA) fall within the limits according to the MoRTH [1] specification shown in Table 5. As the dosage increases beyond 0.2% by weight of mix, the air voids (Va) and voids in mineral aggregate (VMA) value falls above the upper recommended limits. Similarly, in the case of 12 mm and 16 mm length fiber, up to 0.1% dosage, the Va and VMA fall within the recommended limits, and beyond 0.1% dosage, the Va and VMA values fall above the recommended value given in Table 5.

The voids filled with bitumen measure how much bitumen used to find flaws inside the densified aggregate mass. It and the bitumen-void proportion are interchangeable terms. The voids filled with bitumen are crucial since bitumen serves as a good indicator of overall longevity and exhibits a strong relationship with percentage density. Insufficient bitumen prevents longevity as well as causes this to be too dense under vehicle movement and bleed unless the VFA is too minimal. The primary objective of the voids filled with bitumen is to prevent a less long-lasting hot mix asphalt mixture from forming from a thin bitumen coating on the broken stone particles in low-traffic environments.

Figure 8 shows that for fibre lengths of 4 mm and 8 mm up to 0.3% fibre dosage by weight of mix, voids filled with bitumen (VFB) fall within the MoRTH specification shown in Table 5. As the dosage increases beyond the 0.3% dosage by weight of mix, the voids filled with bitumen (VFB) value falls above the upper recommended limits. Similarly, in the case of 12 mm and 16 mm length fiber, up to 0.2% dosage of fiber, voids filled with bitumen fall within the recommended limits, and beyond 0.2% dosage of fiber, VFB values fall above the recommended value given in Table 5.

3.2. Mechanical properties

The prepared Marshall specimen was tested using standard ASTM D 1559 [33], which is described as the peak load borne by the Marshall specimen at a normal test temperature of 60 degrees centigrade. Flow value refers to the specimen's relationship to plastic flow during a Marshall Specimen rupture.

With an increased dose of glass fiber, stability values for all fiber lengths decreased. It was caused by the presence of additional fibers in the mixture, which may also cause sliding between broken stones and lower stability values. The interaction sites between the broken stones used in the asphalt mix decrease with an increased dose of glass fiber, which lowers the stability values [34]. The stability value observed was much higher than the 8.2 kN baseline criteria set by MoRTH for SDBC asphalt mixes throughout all variations, as shown in Figure 9. The least stability observed was 15.7 kN for a mix with 16 mm fiber length at a dosage of 0.40%. The highest stability observed was 22.45 kN for an 8-mm fiber length at a dosage of 0.1%. Higher the stability, higher resistant to fatigue cracking because they are less likely to deform under load [35]. The performance of asphalt mix decreases with increase in dosage of fibre due to reduced workability which make the asphalt mix more stiff and difficult to work with [36].

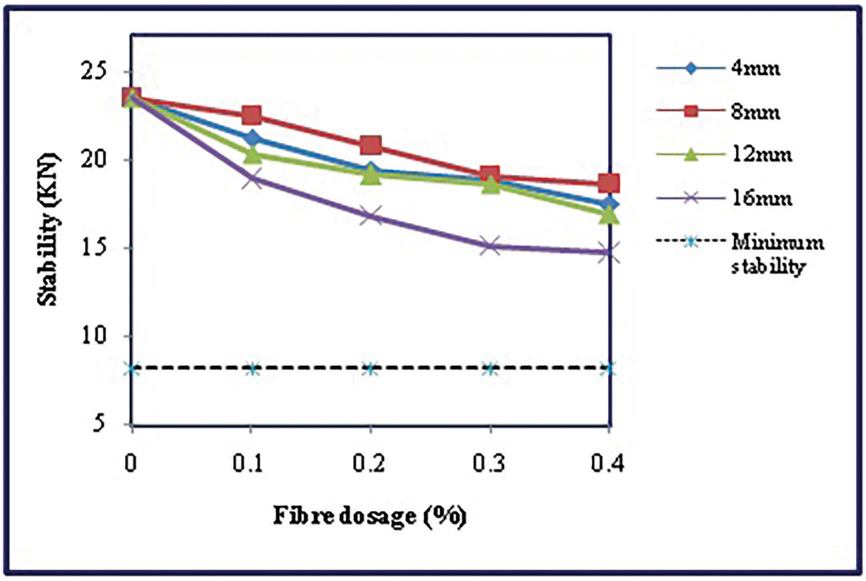

Figure 9: Comparison of stability with various glass fibre doses and lengths in the SDBC asphalt mix.

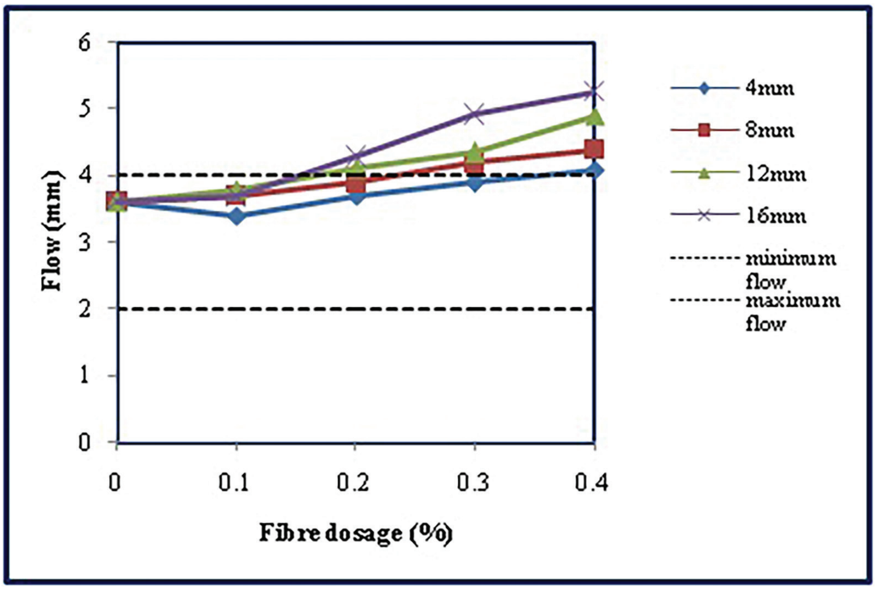

Figure 10: Comparison of flow value with various glass fibre doses and lengths in the SDBC Marshall specimen.

According to Section 500 of the MoRTH for SDBC (semi-dense bituminous mix), the recommended lowest flow value is 2 mm and the highest flow value is 4 mm to achieve a quality asphalt mix for better performance. From Figure 10, for fiber dosages of 0.1%, 0.2%, and 0.3% of 4 mm fiber length, the flow value falls within the recommended lower and upper limit values, while for 0.4% of 4 mm, the flow value exceeds the recommended upper limit. For a fiber dosage of 0.1% and 0.2% of 8 mm fiber length, the flow value falls within the recommended lower and upper limit values, and for a dosage of 0.3 and 0.4% of 8 mm, the flow value exceeds the recommended upper limit. For a fiber dosage of 0.1% of 12 mm fiber length, the flow value falls within the recommended lower and upper limit values, and for a 0.2%, 0.3%, and 0.4% dosage of 12 mm, the flow value exceeds the recommended upper limit. For a fiber dosage of 0.1% of 16 mm fiber length, the flow value falls within the recommended lower and upper limit values, and for a 0.2%, 0.3%, and 0.4% dosage of 16 mm, the flow value exceeds the recommended upper limit. The flow value increases with increase in fibre dosage at lower dosage, beyond that, the flow value decreased due to poor workability of the mix (Meherz *et al* 2005). At the lower dosage of glass fibre volumetric parametres are within the required limit and improved the mechanical properties such as stability, fatigue, indirect tensile strength are improved to greater extend [37].

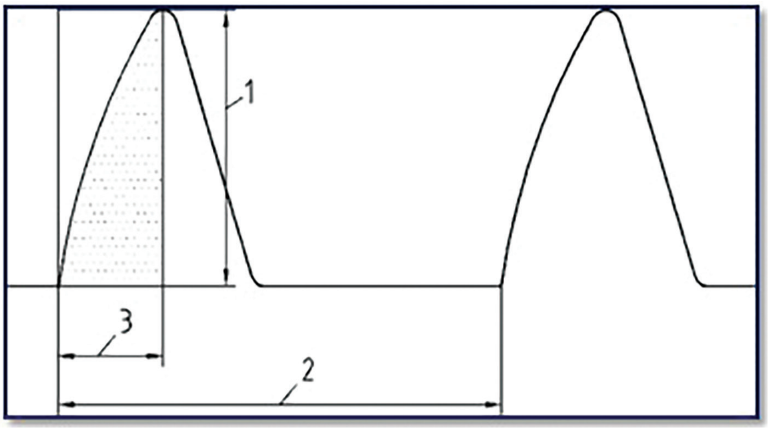

Figure 11: The ITRM loading behavior (1-maximum load 2 -duration of repeating pulse 3- rise time).

Figure 12: The indirect tensile rigidity modulus test arrangement.

Overall ideal bitumen content (OBC) of a control mix (i.e., without fiber) is 5.52%, while the OBC percent for the glass fiber-modified bituminous mix was 5.41%, 5.52%, 5.65%, and 5.71 for doses of 0.1%, 0.2%, 0.3%, and 0.4%, respectively. Various fiber lengths have indeed produced OAC findings (8 mm, 12 mm, and 16 mm). For different lengths and dosages, OAC varied from 5.43% to 5.84%. The OAC was 5.5% by weight of asphalt mixture at a dosage of 0.2% and 8 mm-length glass fiber, which already have greater stability and fulfill all those other required qualities, taking into consideration the strength and volumetric characteristics of all glass fiber lengths and dosages.

4. INDIRECT TENSILE RIGIDITY MODULUS (ITRM)

The indirect tensile rigidity modulus (ITRM) test in accordance with the protocol outlined in BS EN 12697-26 [38], "Hot mix asphalt mixes - Evaluation procedures of hot mixture asphalt - Part 26: Rigidity," that complies with the British standard. Through administering half-sinusoidal stress on the Universal Testing Machine (UTM HYD 25) with such targeted pulse duration, targeted transverse displacement, and a targeted warmth, the cylindrical specimens were subjected to indirect tensile strain for such an investigation. To determine the impact of glass fibers on the rigidity modulus of asphalt mixtures, experiments were carried out on each of the 17 blends, as shown in Table 6, to evaluate glass fibers' impact on asphalt mixtures' rigidity modulus. The typical of loading format is shown in Figure 11 and rigidity modulus test setup is shown in Figure 12.

The estimated rigidity modulus for every load cycle was calculated using observations from the five load cycles by using equation 1 below.

$$S_m = \frac{F \times (v + 0.27)}{z \times h} \quad (1)$$

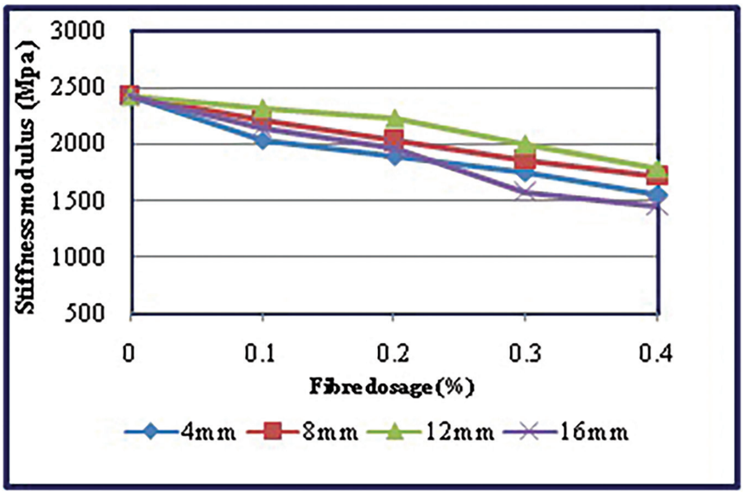

Figure 13: Comparison of stiffness modulus value with various glass fibre doses and lengths in the SDBC Marshall specimen.

Where,

S_m = rigidity modulus in Mpa

F = maximum of compressive force imposed (N)

v = possion ratio

z = the magnitude of the lateral displacement observed throughout the compression cycle (mm)

h = testing samples average girth

Furthermore, it was assumed that all specimens would have a Poisson's ratio of 0.35. Through the use of the given equations, the observed rigidity modulus was converted to a load area ratio of 0.60 by equation 2, given below.

$$S'_m = S_m \times (1 - 0.332 \times (\log(S_m) - 1.82) \times (0.60 - k)) \tag{2}$$

Where,

S'_m − adjusted rigidity modulus to that 0.60 load area value (Mpa)

S_m − at a load factor of k, the measured rigidity modulus (Mpa) @ °C.

k − Assessed load area ratio

The sample taken outside of the testing apparatus, turned 90 degrees around its lateral axis, and its rigidity modulus measured. They replicated the computation and testing. The rigidity modulus of the sample was determined to be the average value of two specimens. The rigidity modulus findings for the control sample and the bitumen mixes with fiber incorporated are shown in Figure 13, and the findings are explained below.

Overall, all fiber length stiffness moduli dropped when the amount of glass fiber increased. Due to the incorporation of glass fibers, the blend appeared to have poorer compressive values, which decreased the rigidity modulus. This enabled the blends to slide between broken stones [37]. The rigidity modulus declined with an increase in fiber dosage, typically with all conceivable configurations of fiber dosages (0.1%, 0.2%, 0.3%, and 0.4% by mass of blend) and fiber lengths (4 mm, 8 mm, 12 mm, and 16 mm). Increased fiber dose lowers the mix's compressive strength, which in turn lowers the stiffness modulus [34]. With the concentration of 0.10% of glass fiber, the rigidity modulus reached its maximum for 4 mm (2037 MPa), 8 mm (2211 MPa), 12 mm (2319 MPa), and 16 mm (2143 MPa), which have been, correspondingly, around 16.17%, 9.01%, 4.57%, and 11.81% lower stiff than the reference samples. At a dose of 0.1% by mass of shattered stones, the rigidity modulus with the maximum value reported to be 2319 MPa for 12 mm fiber length.

5. FATIGUE TEST

This research used the technique outlined according to BS EN 12697-24 [39], "Asphalt mixes - Testing procedure for asphalt hot mix - Part 24: Resistant to Fatigue," to perform fatigue endurance experiments on compacted asphalt specimens.

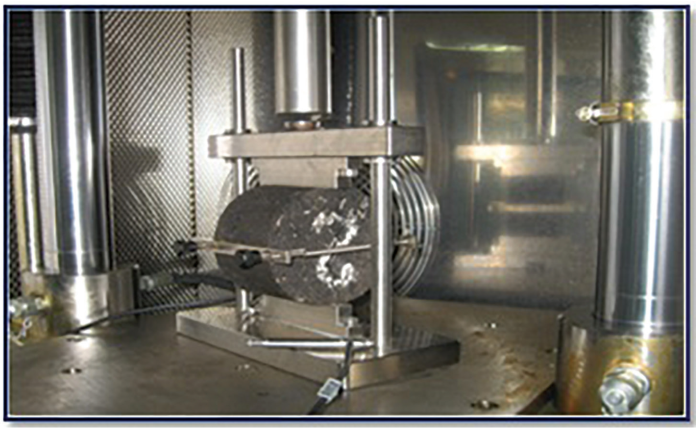

Figure 14: The indirect tensile fatigue test arrangement.

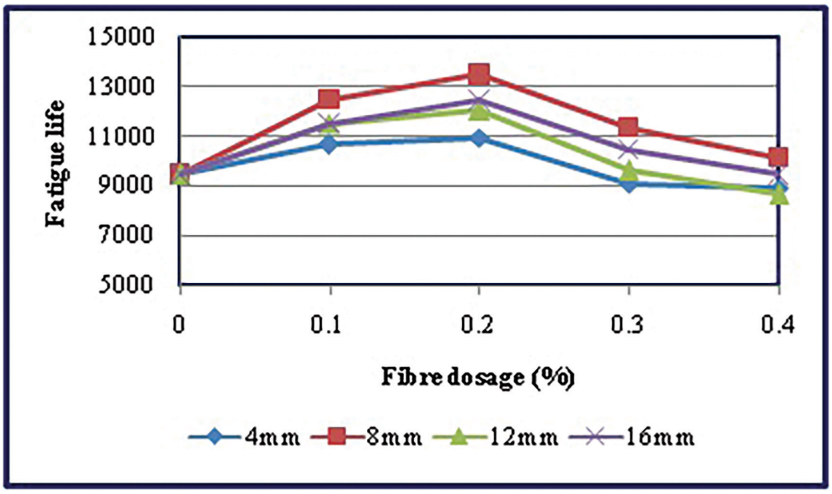

Figure 15: Comparison of fatigue life with various glass fibre doses and lengths in the SDBC Marshall specimen.

Throughout this experiment, the Universal Testing Machine (UTM) applied sinusoidal stress to cylindrical samples. Figure 14 depicts the indirect tensile fatigue test setup that employed in this research. The overall number of loads applied that resulted in full breakage of the sample used to calculate the fatigue performance, as shown in Figure 15. The correlation between the total lateral deformation and the logarithmic number of loading conditions revealed the fracture life.

Figure 15 shows the results of the fatigue tests (periodic load, indirect tensile) that were done in the lab. The reference asphalt mixture's fatigue life lasted 9452 cycles. With fiber doses up to 0.2%, the inclusion of glass fiber substantially enhanced the asphalt blend's fatigue performance. The fatigue performance revealed that there were decreases for all fiber lengths and an increment in fiber concentration of up to 0.2%. According to JAHROMI and KHODAII [40], its longer fatigue performance may have resulted from the fibers' homogeneous distribution throughout the asphalt mixture, resistance to shearing displacement, and suppression of shattered stone movement at lower dosages. Consequently, by postponing fracture onset and propagation and gaining high fracture toughness, the similarity noted in glass fiber contained an asphalt mixture. The fatigue resistance at the dosage of 0.2% with 4 mm (10960 cycles), 8 mm (13450 repitions), 12 mm (12020 repitions), and 16 mm (12418 repitions), which had been approximately 15.98%, 42.33%, 27.20%, and 31.40% greater fatigue life than the conventional asphalt blend, resulted in the maximum fatigue resistance. The optimum fatigue resistance for 8 mm fiber length was observed at a concentration of 0.2% (13450 cycles), which was 42.33% more than the reference asphalt mix. The blend containing 8 mm of fiber length at a concentration of 0.2% showed the longest fatigue resistance. The relation between fatigue cycle and stability of asphalt mix is a complex one that is influenced by the factors such as the type and amount of asphalt binder, the aggregate gradation, the air void content, and the temperature. In general, however, it can be said that the higher the fatigue cycle are observed with inclusion of fibre, which make the mix high stable, the fibre contained asphalt mix can withstand more repeated loading before it fails (RAMESH *et al.* [41]).

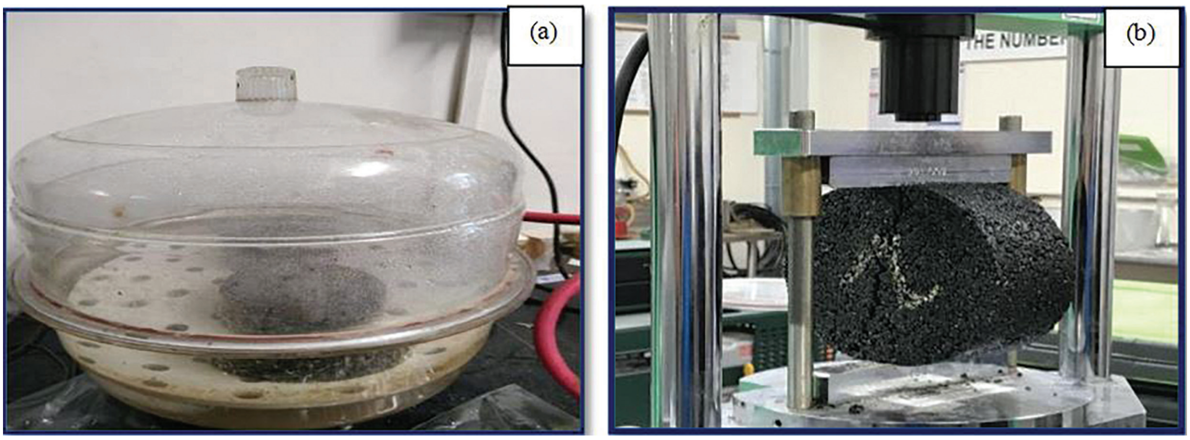

Figure 16: (a) The asphalt specimen kept in the water bath and (b) the indirect tensile strength test setup.

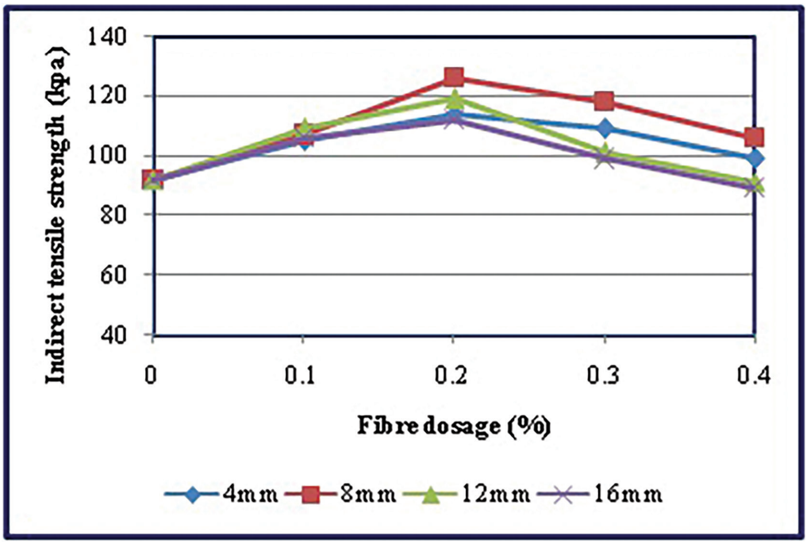

Figure 17: Comparison of indirect tensile strength at 60 ºC with various glass fiber doses and lengths in the SDBC Marshall specimen.

6. INDIRECT TENSILE STRENGTH

The indirect Tensile strength was done accordance with the D6927 [42] and D3549 [43]. According to D6927 [42] -compliant loading machine must be able to deliver a vertical load with a regulated displacement rate while simultaneously monitoring the force and displacement in order to undertake the investigation. Slightly curved iron loading sheets with a tested sample's normal circumference as its curvature radius. The length of the loading strands must be longer than the sample width, and the loading strands' outside ends must be mildly beveled to eliminate jagged corners. The heating system must be sufficient to keep the samples below 61 °C, the experiment temperature. The bituminous sample should have a minimum diameter of 101.6 mm and at least 50.8 mm thickness. According to D3549 [43], thickness of the bitumen specimen must be correct to within 1 mm. The specimen was kept at 61 °C during testing by immersing the specimen in the water for a minimum of thirty minutes and a maximum of 120 minutes, as indicated in Figure 16(a). Once out of the water bath, set the specimen on the lowest loading plate. Lower the top loading pad into minor contact with the sample by gradually lowering it as shown in Figure 16(b). Ensure that the loading bars are parallel and centered. The time between the withdrawal of test specimens from the bath and the final load should not be greater than 2 minutes. Once the ultimate load is attained, apply a vertical ramp force. The suggested rate of displacement is 50 ± 5 mm/min.

Figure 17 illustrate the outcomes of indirect tensile strength at 60 °C done in the lab. With fiber doses up to 0.2%, the inclusion of glass fiber substantially enhanced the indirect tensile strength. The indirect tensile strength at the dosage of 0.2% with 4 mm (114 kpa), 8 mm (126 kpa), 12 mm (119 kpa), and 16 mm (112 kpa), which had been approximately 23.91%, 36.96%, 29.35%, and 21.74% greater indirect tensile strength than the conventional asphalt blend, resulted in the maximum indirect tensile strength. The optimum indirect tensile strength for 8 mm fiber length was observed at a concentration of 0.2% (126 kpa), which was 36.96% more than the reference asphalt mix. The blend containing 8 mm of fiber length at a concentration of 0.2% showed the longest ITS resistance. The increase in ITS with inclusion of fibre, which bridge the gaps between the aggregate particles, which increases the tensile strength of the asphalt mix. Fibers help to distribute the load more evenly throughout the asphalt mix, which reduces the localized stresses that can lead to cracking MAHERZ and KARIM [44], fibers are tough and ductile, which can withstand high tensile stresses without breaking [45]. Overall, fibers are an effective way to improve the indirect tensile strength of asphalt mix. They are strong, ductile, and corrosion-resistant, which makes them well-suited for use in pavements that are subjected to heavy traffic and harsh environmental conditions

7. CONCLUSIONS

From the laboratory investigation of the bituminous mix with 100% copper slag as filler and glass fiber dosages of 0.1%, 0.2%, 0.3%, and 0.4% by weight of the mix, the following conclusions are drawn:

- The stability of bituminous mixes decreases gradually for dosages of 0.1%, 0.2%, 0.3%, and 0.4% with glass and copper slag as filler, but the obtained stability values are greater than the minimum requirement recommended by the MoRTH specification for all the dosages of fiber.
- The fatigue strength of bituminous mixes are increased with glass fiber up to 0.2% with copper slag as filler, beyond that the fatigue life get decreased.
- The indirect tensile strength of bituminous mixes increased with glass fiber up to 0.2% with copper slag as filler, beyond that the fatigue life get decreased.
- The stiffness modulus of the bituminous mix degreased with glass fiber and copper slag as filler.
- Overall, the optimum performance of the asphalt mixture found at 8 mm glass fibre with dosage of 0.2%.

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