Durability Performance of Bitumious MIX with WMA Additives

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Abstract-The durability of a bituminous mix refers to its ability to resist various forms of deterioration over time. Durability is a factor in the performance of bituminous mixed use in road construction. A durable mix resists aging, weathering and traffic loads, ensuring long – lasting pavement. Poor durability can lead to cracks, potholes and surface deterioration, increasing repair costs and reducing road safety. These studies focused on determining the moisture susceptibility using tensile strength ratio and retain Marshall Stability of bituminous mix because in road way design, the moisture susceptibility of bituminous pavement is an important engineering property. Indirect tensile strength (ITS) and Retain marshal stability (RMS) tests are performed on bituminous mixes for evaluating Tensile strength ratio (TSR) and retain Marshall Stability whereas mixes prepared with PMB 76-10 bitumen showed better resistance to moisture damage, and WMA additive such as zycotherm with varying doses with respected toweight of bitumen incorporated at difference production temperature in PMB 76-10 binder. The results show that durability performances of PMB 76-10 bituminous mixes are directly affected by variation of WMA additive doses and production temperature.

Key words-Moisture susceptibility, tensile strength ratio, WMA additive.

I. INTRODUCTION

Pavement service life is one of the most effective parameters in economy of countries. [4][23]. Therefore, one of the primary goals in design and construction of flexible pavements is to gain best performance with regard to stability and durability in optimum conditions [4][21][24]. Environmental factors including temperature and moisture has considerable effect on pavement performance. The presence of moisture or water in the aggregate – binder interfaces reduces the adhesive properties of the asphalt mixtures [4]. Hot Mix asphalt (HMA) is widely used for roads and is a popular choice due to its durability and ability to resist erosion and extreme weather conditions [5].The production of HMA requires large amounts of fuel, which further contributes to climate change and also harms the environment [5]. As a result of this environmental impact, Warm Mix Asphalt (WMA) is becoming more popular reduced production temperatures, which can lead to financial benefits. WMA reduces aggregate heating, mixing, and compaction temperature by 20–40 °C compared to HMA [5][22]. Bitumen is sticky, black and highly viscous liquid or semi solid form of petroleum [2]. A highway has three important components sub grade, base course and surface course [8]. Surface course or pavement is the surface over which vehicles run and other components works as foundation [8], that's why pavement is very important component [8].The presence of moisture cause the early collapse of hit mix asphalt layers which leads to a early deterioration of asphalt pavements [1]. Moisture damages are caused by various factors including properties of asphalt mixture, environmental conditions, construction methods, and so more [1]. In which mainly focused on the evaluation of the effect of warm mix asphalt (WMA) additives on the performance of asphalt mixtures [3]. The durability of bituminous mixtures is crucial for ensuring long- term pavement performance. Traditional hot mix asphalt (HMA) production involves high temperatures, leading to increased energy consumption and emissions. Warm mix asphalt (WMA) additives offer a sustainable alternative by reducing production temperatures while maintaining or enhancing pavement properties [9]. These chemicals are known as " Anti- stripping Agents" or " adhesion promoters" [10]. Since the stability of bituminous pavement largely depends on adhesion between bitumen and aggregates, the iconic nature of aggregate is an important factor explaining the problem of stripping that varies for different type of aggregate [10]. The main goal of anti-stripping additives is to increase the strength and durability of adhesion between aggregate and bituminous binders [10]. Here use Zycotherm as anti stripping agents which is help the bituminous

concrete from water damage [10]. The study assesses their impact on moisture resistance, aging, and mechanical performance, proving insights into their potential for enhancing pavement lifespan and sustainability [10]. The chemical affinity between bitumen and aggregate can be improved by the addition of very quantities of chemical which change the nature of the bitumen or the aggregate to more affinity for the other [10]. Indirect tensile strength (ITS) was conducted according to AASTHO T283 standard on bituminous concrete mixes in it [6]. The Marshall test consists of the manufacturing of cylindrical specimens 102mm in diameter and 64mm high by use of a standard compaction hammer and a cylindrical mould [7]. The specimens are compacted using the compacted effort applicable to the loading conditions [7]. Objective of this study is to evaluate the durability of bituminous mix with adding zycothrem and determine the optimal temperature range that ensures high resistance to moisture damage and moisture damage and mechanical deformation, thereby enhancing pavement performance under diverse climatic conditions.

II. LITERATUREREVIEW

This study evaluates the impact of Warm Mix Asphalt (WMA) additives on asphalt binder performance grade and asphalt mixture performance. It examines Performance Grade (PG), compaction, and field performance using wheel tracking and indirect tensile strength tests. Results indicate WMA additives affect conventional but not polymer-modified binders. WMA pavements generally show better rutting and crack resistance than Hot Mix Asphalt (HMA) pavements [3].The study evaluates the impact of anti-stripping agents on asphalt mixtures to improve moisture resistance and overall pavement performance. It compares Evonik (a new material), Zycotherm (a common nonmaterial), and hydrated lime. Moisture susceptibility was assessed using indirect tensile strength and Texas Boiling tests, while other performance characteristics were evaluated through Marshall, Resilient Modulus, and Dynamic Creep tests. Results indicate that all three additives enhance moisture resistance, with Zycotherm (0.1%) showing the best performance. Hydrated lime was most effective in improving rutting resistance due to its hardening effect [4].The asphalt industry consumes large amounts of fuel and emits pollutants. Warm mix asphalt helps reduce these impacts but raises performance concerns. This study evaluated the properties of three bituminous binders modified with chemical additives. Results showed that while additives do not reduce binder viscosity, they improve mixture compact ability, lowering production and compaction temperatures [9].This study investigate the moisture susceptibility of warm mix asphalt(WMA) ,a concern due to it's lower production temperature potentially impacting aggregate drying, binder adhesion and stiffness. Using bitumen bond strength (BBS) and dynamic modulus tests, researchers evaluated how these factors influence moisture resistance. By comparing hot mix asphalt (HMA), WMA, and WMA without additives, the study found that certain WMA additives can enhance adhesion and offset the negative effects of reduced temperatures. The finding support incorporating new testing methods into WMA design and emphasize the importance of selecting suitable additives to improve moisture resistance in WMA[12]. Studies indicate that warm mix asphalt (WMA) technology effectively lowers the high production temperature of rubberized asphalt (RA) mixtures, offering environmental benefits like reduced noise and improved performance. This study explores two organic WMA additives slack wax (SW) and polypropylene Wax (PPW) which reduce RA viscosity and lower mixing and compaction temperature by 20-25 C when added at 6% of binder weight. Tests showed both additives enhance stiffness but slightly reduced moisture resistance, though most specimens still met minimum standard. The findings suggest SW and PPW are viable, cost effective options for warm RA mixes in hot, dry regions, though further research is recommended[15].

Moisture damage is a major concern for asphalt pavements, especially when using warm mix asphalt (WMA) technologies that operate at lower temperature. This study examined the moisture resistance of asphalt mixture using various tests like bond strength ratio (BSR), percentage coating, retained Marshall stability (RMS), and tensile strength ratio(TSR). It considered two types of aggregate, two asphalt binder (VG30 and PMB40) , and five WMA additives from organic, chemical and foaming categories. Results showed that moisture resistance varied with aggregate type and binder, with the chemical additive rediset offering the best performance. A strong correlation was

observed between BSR and TSR , and a minimum BSR of 0.7 is recommended for adequate moisture damage resistance[16]. This study investigates the physical , thermal and environmental characteristics of polymer modified asphalt binder (PG76) with warm mix asphalt (WMA) additives. While polymer modification raise asphalt's mixing and compaction temperature above 150C, WMA helps reduce them, improving workability and environmental performance. Physical and thermal tests confirmed that the mixes remained stable above their working temperatures, with decomposition starting above 360C. contact angle analysis showed increased water spreading with more WMA, indicating a more hydrophilic surface. Leaching tests simulated rain exposure, and ICP-MS analysis of heavy metals revealed no significant environmental contaminaton, supported by multiple pollution indices[17].

Warm Mix Asphalt (WMA) technology, which uses chemical additives like Zycotherm, reduces asphalt pavement temperature s, saving energy and benefiting the environment. This study compares the Marshall properties of WMA with Zycotherm (0.1% by binder weight) to improve stability and workability while reducing Optimal Binder Content (OBC). The results show enhanced stability and overall pavement performance, making WMA a promising alternative to conventional asphalt [2].The study evaluates the impact of anti-stripping agents ZycoTherm (Zyc) and Evotherm M1 (EM1) on Warm Mix Asphalt (WMA) using conventional and advanced laboratory tests. While conventional tests showed minor changes, rheological analysis indicated improved rutting and fatigue resistance, especially with 0.05% Zycotherm Chemical composition analysis revealed changes across aging conditions [5].in India , roads play a vital role in transportation and economic growth , with a vast network of over 4.86 million kilometers, mostly comprising flexible pavements. These pavements typically last 10-15 years but are affected by factors like traffic, climate, materials, and subgrade strength. Common defects such as potholes and cracking necessitate regular maintenance. Studies suggest that adding admixtures like fly ash or HDPE can enhance pavement durability. This study explored the effect of zycotherm , a chemical admixture, on dense bituminous macadam(DBM) grade II. Result showed that zycotherm- modified bitumen improved marshall stability and flow mix, indicating enhanced pavement performance[11]. Good adhesion between bituminous film and aggregate is crucial for long lasting bituminous pavements. Stripping, the loss of this film due to water on hydrophilic aggregates, leads to failures like rutting and cracking. This study evaluated two types of liquid anti striping agents (silicon based and anime based) in bituminous concrete using three methods : modified lottman test, surface free energy, and Texas boiling test. Results showed that anti stripping agents effectively reduced moisture susceptibility, with zycotherm at 0.05% performing the best[18]. This research aims to enhance current practices by evaluating various test methods to assess moisture damage in bituminous mixes, addressing both short and long term industry needs. It explores key factors such as bitumen chemistry, aggregate properties, and the role of anti stripping additives like wet bond-s, zycotherm, and Bitugrip. Laboratory tests, including boiling water and stripping value tests, were conducted with different concentration of these additives to determine their effectiveness. Results show that increasing the percentage of anti stripping agents improves moisture resistance and reduce stripping, ultimately enhancing the adhesion between bitumen and aggregate[20].

The study evaluates the moisture susceptibility of bituminous concrete (BC) mixes using VG30 and CRMB55 binders. Indirect tensile strength (ITS) tests per AASHTO T283 revealed that VG30 mixes failed to meet the 80% tensile strength ratio requirement, while CRMB55 mixes performed better. The use of an anti-stripping agent (ASA) at 0.05% and 0.075% improved moisture resistance, even under prolonged conditioning [6].This study applies neural networks (NN) to predict Marshall test results for polypropylene (PP) modified asphalt mixtures. PP fibers enhance the asphalt's mechanical properties, improving Marshall stability and stiffness. The NN model predicts stability, flow, and Marshall Quotient using specimen properties. A formulated model and parametric analyses further validate the approach for researchers [7].Bituminous hot mix is a widely used but expensive flexible pavement layer. Engineers are exploring cost-effective alternatives while maintaining strength, stability, and durability. Fillers play a crucial role in improving pavement performance, but conventional fillers like cement and lime are costly. Researchers are investigating waste materials such as fly ash, bagasse ash, marble dust, and foundry sand as

substitutes. Studies show that these materials can partially or fully replace conventional fillers while delivering satisfactory results. This study examines the impact of these alternative fillers on the Marshall hot mix design properties [8].mineral fillers significantly influence the performance of asphalt mixes, with various types used globally. In Kuwait, the primary fillers are ordinary Portland cement(OPC) and pulverized limestone. This study compared their effect on asphalt mix strength using Marshall stability and retained strength tests at filler content of 4%,5% and 6% by weight of aggregate. Result indicated that while both fillers similarly affected Marshall stability, OPC provided higher retained strength values[13]. This study examined the mechanical and durability performance of warm mix asphalt(WMA) mixtures with 0% and 50% reclaimed asphalt pavement (RAP) using different WMA additives – sasobit, kaowax, zeolite and PAWMA. Mechanical tests showed performance varied by additive type, with PAWMA negatively affecting moisture resistance. RAP inclusion reduced flexibility and cracking resistance but improved rutting resistance. The RAP kaowax mix showed the highest flow number, while the HMA-zeolite mix had the lowest. RAP improved moisture resistance overall, with RAP PAWMA mixture performing best in this regard. Additionally, RAP mixes with sasobit and PAWMA showed superior modulus and cracking resistance, respectively[14]. This study investigates how warm mix asphalt (WMA) production impacts moisture damage susceptibility, focusing on adhesion at the asphalt aggregate interface and binder stiffness. Using bitumen bond strength (BBS) and dynamic modulus ratio tests, researchers evaluated the effects of reduced production temperatures and residual moisture in aggregates. Results showed that while WMA can increase moisture susceptibility due to lower binder stiffness and less effective drying, certain WMA additives enhance moisture resistance, helping to counteract these issues. The study suggests incorporating BBS and dynamic modulus tests into WMA design specifications to better assess and mitigate moisture damage risks[19].

III. MATERIALS AND EXPERIMENTAL

MATERIAL:-

The materials used In, including aggregate, bitumen, and additives. High-quality, angular aggregates provide better interlocking and resistance to cracking, enhancing tensile strength. The type and grade of bitumen affect the mix's flexibility and adhesion properties, with modified bitumen(like polymer-modified) often yielding higher TSR values additionally, WMA additives are commonly added to improve moisture resistance, which helps maintain tensile strength under wet conditions. Overall, the careful selection and proportioning of materials are crucial for archiving a high TSR, indicating a durable and moisture-resistant bituminous pavement.

BITUMEN:-

Bitumen a black, sticky, and highly viscous liquid or semi-solid form of petroleum used primarily in road construction and waterproofing. Bitumen binds aggregates together, making it essential in asphalt pavement production. It's durability, water resistance, and adhesive properties make it suitable for various industrial applications. Physical property of PMB 76-10 given in table-1 Polymer Modified Bitumen (PMB) is a blend of conventional bitumen and polymers that enhances the binder's elasticity, durability, and resistance to deformation .The bituminous mix (polymer modified bitumen PMB76-10) used in this study was supplied by MARUTI BITUMEN PVT.LTD.

BITUMINOUS MIX:-

A bituminous mix, also known as asphalt mix, is a composite material used primarily for constructing and maintaining roads ,airports, and parking lots. In this study, polymer Polymer modified bitumen (PMB76-10) was used to enhance the performance characteristics of the asphalt mixture as a binder, mixed with aggregates such as course aggregate , fine aggregate . The mix provides a durable, flexible, and weather-resistant surface that can withstand heavy traffic loads. Different types of bituminous mixes, such as warm mix asphalt (WMA), are used in it based on application requirements and environmental conditions.

Table 1: Physical property of PMB 76-10.

Test parameter	Unit	Specification IS 15462:2019	Result
Tests to be Carried out on Original Binder			
Softening point (R and B)	C	Min 70	78
Elastic recovery of half thread in Ductilometer at 15'C	%	Min 70	75

Flash point	C	MIn 230	288
Viscosity at 150'C	Pa.s	Max 1.2	1.178
Complex modulus (G*) divided by Sin delta (G*/sin) as min 1.0 k.Pa, 25 mm Plate, 1mm Gap, at 10 rad/s, at a temperature,70' C	Kpa	Min 1.0	2.086
Phase Angle	Degree	Max 75	63.6
Separation, difference in softening Point,(R&B)	C	3.0 Max	0.9
(B) Tests to be carried out on rolling Thin Film Oven (RTFO) Residue^2)			
Loss in mass	%	Max 1.0	0.14
Complex modulus (G*) divided by Sin delta (G*/sin) as min 2.2 k.Pa, 25 mm Plate, 1mm Gap, at 10 rad/s, at a temperature,76' C	Kpa	Min 2.2	3.467
MSCR TEST ,jnr 3.2 at 76 C	Kpa	Max 4.5	0.6180
MSCR TEST ,jnr diff, at 76 C	Percent	Max 75	35.49

ZYCOTHERM:-

Zycotherm is a proprietary warm mix asphalt (WMA) additive, designed to enhance the performance and workability of asphalt mixture at lower production temperatures. By promoting improved adhesion between bitumen and aggregates, Zycotherm enables asphalt to be mixed and compacted at temperatures 20–40°C lower than conventional hot mix asphalt. This temperature reduction results in significant energy savings, lower greenhouse gas emissions, and improved working conditions for paving crews. Additionally, Zycotherm-treated mixes often exhibit enhanced moisture resistance and long-term durability, making them suitable for a wide range of climates and traffic conditions. a strong chemical bond at the bitumen-aggregate interface, contributing to improved pavement performance and sustainability.

Table 2: Physical Properties of Polymer Modified Bitumen (PMB-76-10) with zycotherm additive

Sr NO.	Test Name	RESULT Zycotherm does 0 %	0.05 %	0.1 %	0.5 %	Specification as per MORTH -V and (IRC SP-53-2010)
1	Penetration at25℃, 100gm,5Sec.	33	31	38	45	30-50(mm/10)
2	Softening Point	72	65	63.5	59	60℃min.
3	Flash Point,COC,℃	253	256	263	267	220℃min.
4	Elastic recovery of Half thread in Ductilometer at15℃	70	65.5	60.5	51.5	70%min. (70mm)
Thin film test and Tests Residue.						
5	Loss in mass	0.81	0.49	0.40	0.34	1%max.
6	Increase in softening point	71	56	58	61	5℃max. (65℃)
7	Reduction in penetration of residue at25℃	6.06	3.22	15.78	24.44	35%max
8	Elastic recovery of half thread in Ductilometer at25℃	69	54	57	58	50%min. (50mm)

AGGREGATE

Aggregates are essential materials in road construction, providing strength, stability, and durability to pavement structure. Comprising crushed stone, gravel, sand, or recycled materials, aggregates form the foundation and surface layers of roads. They distribute loads, enhance skid resistance, and ensure proper drainage. The quality, size, and gradation of aggregates significantly influence the performance and lifespan of the roadway.

Table 3: Physical property of aggregate: -

Test	Results	MORTH Specifications
Impact value Test	11%	<24%
Specific gravity Test	2.2465	>2%
Abrasion	26%	<30%

value test		
Water absorption test	0.45%	2%max
Flakiness and elongation test	29.4%	35%

Sustainable use, including recycling old pavement materials, also supports environmental goals in modern road construction. Aggregate used in this study was supplied by PAVAN CONSTRUCTION CO. (PCC).

IV. EXPERIMENT

Mix Design :-

In this process of classifying aggregate particles based on their size using sieves to ensure a proper mix of different size for better compaction, strength and durability. In this study, a combination of 10 mm and 6 mm size aggregates along with quarry dust was used to achieve better compaction of the bituminous mix. The graded aggregate blend helps improve the interlocking and packing density, resulting in enhanced stability and durability of the pavement.

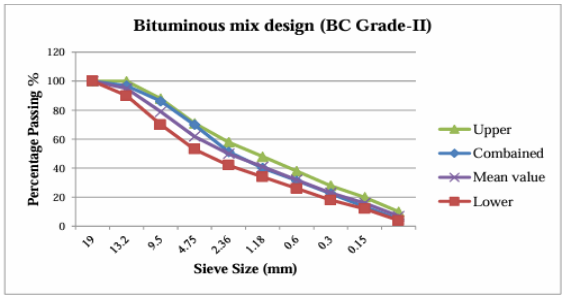

Figure 1: gradation for bituminous mix grade II

In this study, the optimum binder content was determined using 82.05 grams of bitumen, which provided the best balance of strength, durability, and workability for the mix design. This binder content ensured adequate coating of aggregates while maintaining desired compaction and stability. The selected amount also minimized the risk of rutting and bleeding, contributing to enhanced performance and longevity of the pavement structure. In this study, a bituminous mix was prepared using a total of 1200 grams of materials to achieve better compaction. The mix consisted of 300 gm of 10 mm aggregates, 360 gm of 6 mm aggregates, 540 gm of stone dust, and 82.05 gm of bitumen. This specific combination was selected to optimize the gradation and binder content, ensuring enhanced stability, strength, and compaction of the bituminous mix.

The marshall mould casting procedure is a standardized method used to evaluate the quality and performance of asphalt mixtures in road construction. WMA additive is selected including: Chemical additive (ZYCOTHERM).

Design a bitumen concrete (BC) grade-II for conventional bituminous mix with zycotherm (with a fixed dose of 0.05%, 0.1% and 0.15%) at a compare temperature of 165*C and 135*C.

Table 4: Mixing and compaction temperatures of modified binders

BINDER	MIXING TEMPERATURE	COMPACTION TEMPERATURE
PMB76-10	165	150

RETAIN MARSHALL STABILTY TEST

Perform Marshall Retained Test on the conventional bituminous mix and the modified mix consisting of Zycotherm Analysis of data and formulation of result.

The Marshall Retained Stability Test evaluates the moisture susceptibility and stability of bituminous mix. In this process, maintain 6.5% air voids, proper compaction is essential. Controlled compaction helps in locking aggregate particles together, reducing voids without over – compacting, thus preserving the required air voids content. This approach results in better durability, improved performance, and long term pavement stability. Standard Marshall specimens are prepared and divided into two groups: one is tested in dry conditions while the other is conditioned by immersing in water at 60°C for 24 hours. After conditioning, both sets are tested for Marshall stability using a loading frame. The retained stability is calculated as the ratio of the stability of the conditioned specimens to the unconditioned ones, expressed as a percentage. A higher retained stability indicates better resistance to moisture-induced damage, which is crucial for assessing the durability of the mix in wet conditions.

RETAIN MARSHALL STABILITY TEST:-

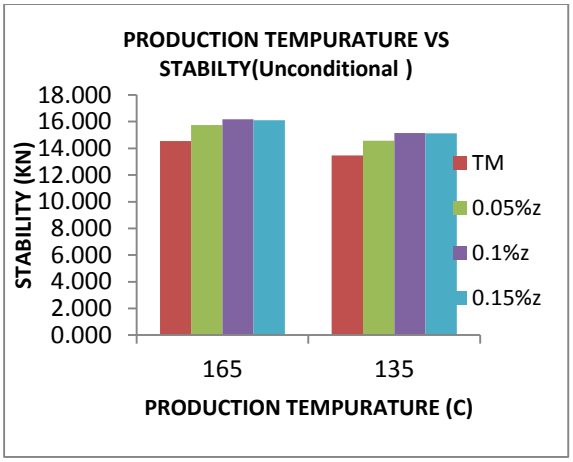

Figure2: PRODUCTION TEMPURATURE VS STABILTY (Unconditional)

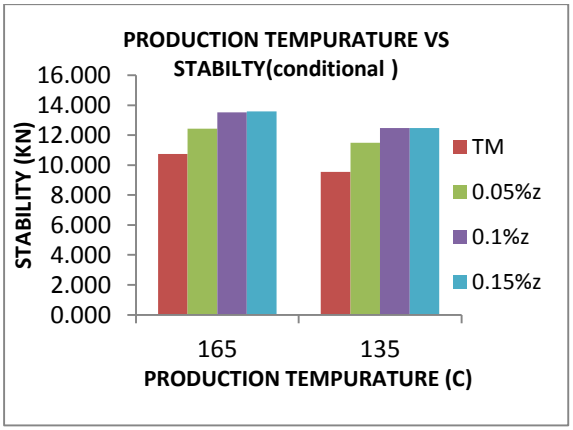

Figure 3: PRODUCTION TEMPURATURE VS STABILTY (Conditional)

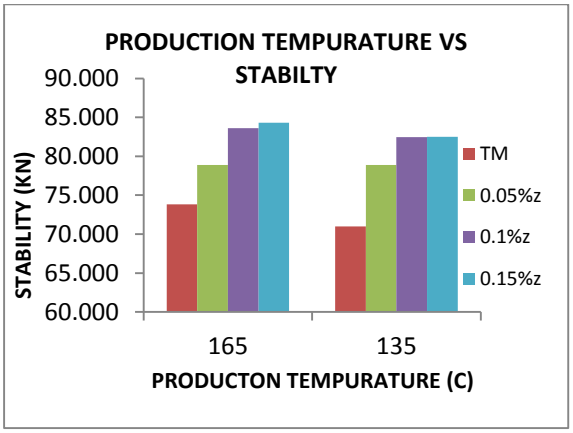

Figure 4: PRODUCTION TEMPURATURE VS STABILTY

The temperature vs. stability graph typically shows an increasing trend where stability rises with temperature. This behavior indicates that as temperature increase, the binder in the WMA becomes more workable and cohesive, enhancing the overall compaction and inter- particle bonding. In the short term, this leads to improved load-bearing capacity and higher Marshall stability values, reflecting better resistance to deformation under applied loads. This trend highlights the benefits the benefit of WMA technologies, which allow for effective performance even at 135C lower production temperatures compared to hot mix asphalt.

TENSILE STRENGTH RATIO

The tensile strength ratio (TSR) of a bituminous mix is used to evaluate the moisture susceptibility of asphalt mixtures. The process involves preparing compacted bituminous specimens and dividing them into two groups: conditioned (subjected to moisture conditioning, In this study, maintaining 7% air voids in the bituminous mix was found to be optimal for achieving better compaction and improved durability. Typically via partial vacuum saturation and freezing-thawing cycles for 18hour at -18C temperature then after put in hot water for 24 hours at a 60C temperature) and unconditioned. Both groups are tested for indirect tensile strength using a compression testing machine. The TSR unconditioned specimens, expressed as a percentage. A higher TSR indicates better resistance to moisture- induced damage, which is critical for pavement durability.

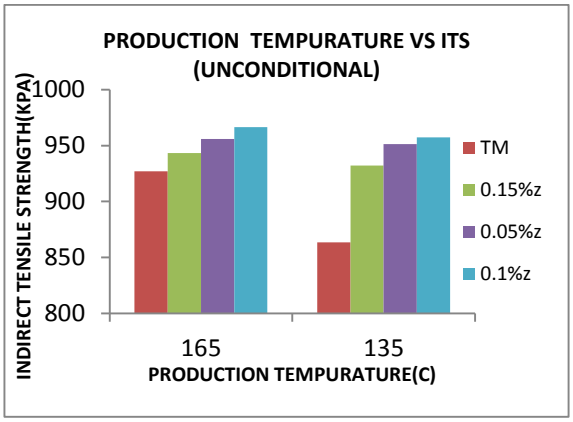

Figure 5: PRODUCTION TEMPURATURE VS INDIRECT TENSILE STRENGTH (UNCONDITIONAL)

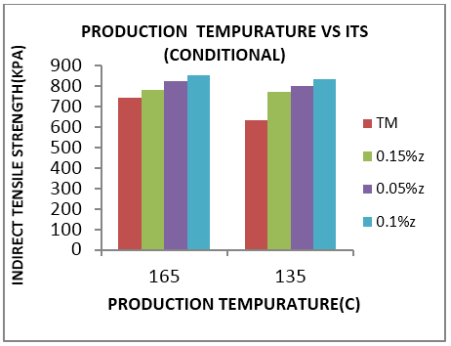

Figure 6: PRODUCTION TEMPURATURE VS INDIRECT TENSILE STRENGTH (CONDITIONAL)

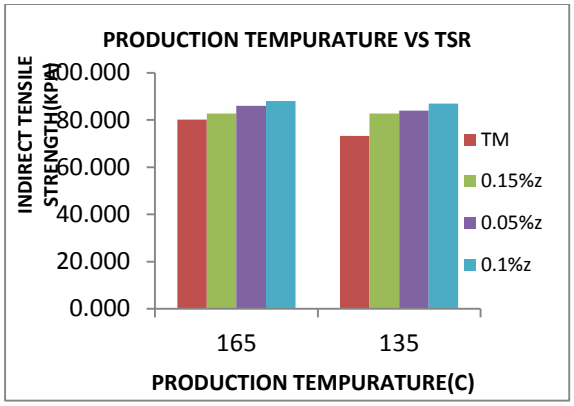

Figure 7: PRODUCTION TEMPURATURE VS TENSILE STRENGTH RATIO

the relationship between temperature and the tensile strength ratio (TSR) of a bituminous mix incorporating warm mix asphalt(WMA) additives and technology typically shows a positive trend. As the temperature increases, the TSR also tends to increase, indicating improved moisture resistance and durability of the mix. At lower temperature, the TSR values are relatively lower, suggesting reduced bonding between aggregates and the binder. However, with the application of WMA additives and awrm mix technology, the mix technology, the mix demonstrates enhanced performances, thus improving the tensile strength ratio. The overall curve reflects the effectiveness of warm mix technology in maintaining or enhancing the mechanical properties of asphalt mixture across a range of temperature.

V. CONCLUSION

The PMB76-10 + zycotherm initial research and analysis shows promising results in terms of durability and environmental benefits. The incorporation of warm mix additives and the application of warm mix asphalt(WMA) technology demonstrated a positive influence on the moisture susceptibility and durability of bituminous mix. The tensile strength ratio (TSR) values for WMA mixes were observed to be within acceptable limits (typically>80%), indicating satisfactory resistance to moisture-induced damage. Similarly, the retained Marshall Stability of the WMA- modified mixes showed minimal reduction compared to hot mix asphalt (HMA), confirming that the structural stability of the mix is retained even under moisture conditions.

Overall, the use of WMA technology not only reduces production temperatures and environmental impact but also maintains essential performance characteristics, making it a sustainable and effective alternative to conventional HMA.

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