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Utilization of Zycotherm-SP2 on Warm Mix Asphalt Concrete - A Modern Technology

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Abstract*— The increase of environmental concerns has been a promising force behind the existing study on zycotherm-SP2 (ZT-SP2) as part of the possibilities to decrease air pollution in the construction sector through the use of warm mix asphalt (WMA) modern technology. This paper, therefore, provides a modern technology for using ZT-SP2 on WMA concrete. The novel aspect of this work is the alteration of asphalt binder by the use of a ZT-SP2, a revolutionary warm mix additive product. With the help of the eco-friendly material ZycoTherm, asphalt may be produced at lower temperatures between 10 and 15 degrees Celsius, and at lower densities between 30 and 40 degrees Celsius. Published research has shown that adding CBA improves the structural performance of asphalt concrete pavements. Several studies have been made to enhance many types of WMA technologies (chemical, organic, and foaming additives) however, conflicting outcomes have been reported for several recognized features. All experiments were done in a laboratory setup. The summary of the results showed that the use of a ZT-SP2 dose of not more than 0.1% enhances the performance of WMA concrete. An additional in-situ study is needed to prove the performance of ZT-SP2 in real situations.

Keywords*— Environmental concerns, WMA concrete, WMA modern technology, zycotherm-SP2, and other additives.

I. INTRODUCTION

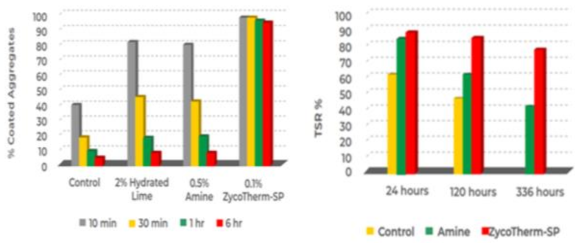
With the help of the eco-friendly material ZycoTherm, asphalt may be produced at lower temperatures between 10 and 15 degrees Celsius, and at lower densities between 30 and 40 degrees Celsius. To create asphalt mixtures, several WMA technologies are currently in use, and more are being developed [1][2][3][4][5]. Three recognized techniques are used to create WMA mixes: foaming procedures, chemical additions, and organic additions [6]. The influence of 0.10% and 0.30% Evonik, 0.10% and 0.30% zycotherm, and 1.0% and 2.0% hydrated lime by the weight of bitumen against moisture vulnerability on bituminous mixes were investigated by Ameri et al (2018) [7]. The outcomes of the investigation showed optimum proportions of 0.30%, 0.10%, and 2.0% for Evonik, zycotherm, and hydrated lime respectively. These optimum proportions distinctly influenced moisture weakness substantially. As stated by Hasani Nasab et al. [8], bitumen can be produced at lower temperatures, between 10 ^{0}C and 15 ^{0}C, and bitumen densities, between 30 ^{0}C and 40 ^{0}C, thanks to Nano-ZycoTherm, an environmentally friendly material. According to Ameri et al. [7] utilizing a lower dosage of ZycoTherm in a WMA combination performs better than normal anti-stripping for all types of aggregate. In summary, ZycoTherm is an environmentally safe additive that is odorless, water-mixable, non-flammable, slightly acidic, and non-corrosive [9]. As of right now, it is possible to use less petroleum and lower the construction temperature of the asphalt mixtures thanks to the development of the WMA approach [10]. According to Kumar & Saxena [11], ZycoTherm is an odorless additive that lowers production and compaction temperatures by up to 65 ^{0}F by increasing moisture resistance. Waste motor oil-containing WMA is said to perform noticeably better than conventional blends, according to Eltwati et al. [12] Because the warm mixture cools more quickly to the proper production and compaction temperature, road users can use the construction site sooner. Conversely, WMA is composed of bitumen, water, and virgin aggregates (additives may be used as needed). Consequently, the WMA combination is prepared at the appropriate production temperature of between 100 and 150 degrees

Celsius [13][14][15].

WMA is made at a lower temperature than HMA [16]. The ambient mixing and production temperatures of WMA provide a more comfortable work environment for asphalt workers [12][17][18]. Similarly, the emission of fume and smell is decreased by approximately 50% with a production temperature of 12 ^{0}C and a compaction temperature reduction [18][19]. Studies by Kumar & Coleri [18] and Yousefi et al. [20] show that the amount of warm mix additives to be used in the asphalt mixes controls the bitumen and aggregate contents as well as the mixtures' primary qualities. Fig. 1 shows a new product of ZT-SP2 commonly used for WMA concrete.

Fig. 1. ZT-SP2 for WMA concrete

Alam & Aggarwal (2020) [21] examined the influence of zycotherm as an agent of anti-stripping. The research outcomes have shown that incorporating zycotherm aids in enhancing the worsened adhesion in asphalt concrete. Mirzababaei (2016) [22] investigated the influences of zycotherm with 0.10 percent on moisture vulnerability in WMA concrete made with two grades of calcareous and siliceous particles. The outcomes of the investigation revealed that zycotherm improved the behavior in response to moisture vulnerability regardless of gradations and type of aggregates used [23]. Kavussi & Bakhtiari (2014) [24] discovered the influences of nanomaterials on resistance to moisture of bituminous mixtures. The findings of the study showed that a mixture of zycotherm (0.1%), hydrated lime (2.0%,) and amine (0.5%) produced supreme tensile strength ratio (TSR) values. Fig. 2 shows the water boiling test conducted according to ASTM D3625 and the TSR comparison of the said warm mix additives.



(a). Water boiling test (b). TSR comparison

Fig. 2. Water boiling test and TSR comparison of warm mix additives

Alam & Aggarwal (2020) [21] studied the effects of moisture vulnerability on bituminous mixtures using zycotherm and crumb rubber. The dosage of four percent of zycotherm by weight of bitumen showed better-quality effectiveness in preventing moisture susceptibility [25]. Similarly, 2.0% and 4.0% zycotherm mixed with bitumen, however, did not exhibit any substantial variance in the bituminous mixtures, though enhanced TSR values are detected irrespective of aggregate types [26]. Fig. 3 shows the behavior of the anti-stripping additive (zycotherm) on moisture damage of hot mix asphalt (HMA).

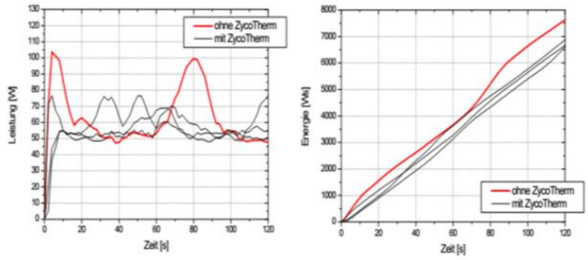
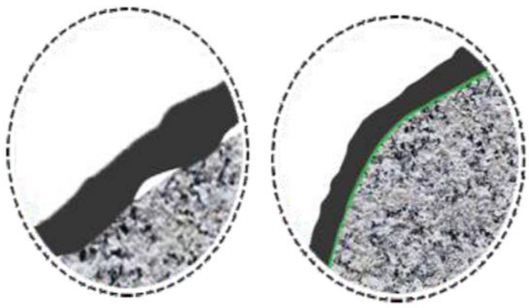


Fig. 3. Behavior of anti-stripping additive (zycotherm) on HMA [27]

The comprehensive aggregate coating by zycotherm -modified bitumen also results in zero pinhole mixtures that have decreased anti-stripping and oxidative possibilities [28]. Fig. 4 shows the coating of ZT-SP2-modified bitumen with the aggregate surface. The increase of environmental concerns has been a promising force behind the existing study on ZT-SP2 as part of the possibilities to decrease air pollution in the construction sector through the use of WMA modern technology. This paper, therefore, provides a modern technology for using ZT-SP2 on WMA concrete. The novel aspect of this work is the alteration of asphalt binder by the use of ZT-SP2, a revolutionary warm mix additive product.



(a). Without ZT-SP2 (b). With ZT-SP2

Fig. 4. Coating of ZT-SP2-modified bitumen with the aggregate surface

A.Properties of Zycotherm

The rising knowledge of and demand for viability philosophies in roadway engineering over the past 20 years has improved the development and application of various WMA techniques [29]. ZycoTherm-TM application has enhanced WMA pavement fabrication in the construction

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sector [30]. The performance of WMA-modified containing lime, ZycoTherm, and ZycoTherm-TM additives not only results in fewer compaction determinations when compared to conventional mixture assessments, but it also offers superior resistance to pavement distresses and steadiness of mixing, albeit at a lower temperature [30][31]. Singh et al. [32] claim that ZycoTherm and changing the sulfur content of the asphalt binder enhances the performance of modified mixtures over a broad temperature range. Eltwati et al. [12] discovered that the moisture resistance of mixtures prepared from spent engine oil was enhanced by the addition of 0.1% ZycoTherm. Further research by the previously mentioned researchers revealed that the waste engine oil-rejuvenated mixes treated with 0.1 percent ZycoTherm exhibited improved resistance to rutting in a wet process when compared to both conventional hot mixtures and waste engine oil-rejuvenated mixes. Nevertheless, the reinvigorated mixtures modified with ZycoTherm were less effective at rutting in a dry process.

According to Singh et al. [32], using 0.1% ZycoTherm as an antistripping agent for nanotechnology enhances the ability to make WMA mix at lower temperatures and increases the functionality and compressibility of special materials used in Malaysia. According to Wróbel et al. [33] one of the most crucial scientific considerations while constructing an asphalt road is the compaction index. The compaction index can be negatively impacted by climatic circumstances, mixture temperature, and poor configuration of asphalt paving equipment. If the asphalt pavement's temperature is lowered, less energy would be needed to produce asphalt mixtures [33][34][35]. A new warm mix additive product for warm mixtures is the ZT-SP2. Without zycotherm, the mixture creates a polar interface between aggregate and bitumen, and 5 percent to 15 percent of bitumen contributes to bonding (Fig. 4(a)). However, with zycotherm, the mixture has excellent bonding between aggregate and between (Fig. 4(b)). Furthermore, without zycotherm, the bitumen is feebly bonded to great resistance against paving rutting [22]. Table 1 depicts the properties of the zycotherm.

Table 1. Properties of zycotherm [32]

S/N	Properties	Unit	Outcomes
1	Density	g/mol	1.01
2	Viscosity at 25 °C	cP	300
3	Color	-	Pale yellow
4	Flash point	°C	>80
5	PH value	%	Ten soluble in water or slightly acidic
6	Solubility	-	Miscible with water
7	Freezing point	°C	5
8	Odor	-	Slight aromatic
9	Specific gravity	-	0.97
10	Physical state	-	Liquid

II. MODERN TECHNOLOGY AND PERFORMANCE OF WMA MIXTURE

Nowadays, WMA has been extensively used everywhere in the world and has numerous engineering applications [36]. The overview of the WMA modern technology has legalized a lesser production temperature of the WMA mixture, lessening air pollution, and less consumption of petroleum [37]. WMA is produced at a lesser temperature compared to the distinctive production temperature of HMA mixes [38]. Lesser production and compaction temperatures lessened petroleum consumption rate, resulting in momentous cost discounts [39][40]. The reason for this lesser energy strength is that, WMA produces minor greenhouse gas (GHG) quantities than HMA [39]. Different complications in the production of asphalt concrete can be efficiently resolved by the modern application of chemical, organic, and foaming agents [19]. Mirzababaei (2016) [22] made a comparison of the influence of zycotherm on the moisture susceptibility of HMA and WMA mixes with two categories of aggregates (siliceous and limestone) by using resilient modulus, indirect tensile strength (ITS), and water boiling tests. The overall outcome of the study showed that zycotherm has an optimistic influence on the behavior of WMA mixtures.

In WMA modern technology, warm mixtures are assorted and compressed at a lower temperature [41]. Depending on the types of production equipment and various additives, the suggested temperature reductions vary from 15 ^{0}C to 80 ^{0}C [42]. This temperature reduction originates from the modern technologies established in the last two eras as well as the utilization of several warm mix additives regarded as chemical, water-based, and organic modern technologies of WMA [43][20]. As a result of the decrease in the production and compaction temperatures, the performance features of the WMA mixture are fully transformed for sustainable utilization [37]. Fig. 5 shows the paving of WMA at a lower compaction temperature.

Fig. 5. Paving of WMA at lower compaction temperature

However, other warm mix additives are used to make WMA mixes discharge water to reduce the viscosity of bitumen, which reduces the strong bond between the aggregate and bitumen [44]. The presence of zycotherm in the WMA mixture shows that the infiltration of the modified bitumen after production has judgmentally enhanced the performance of WMA concrete compared to the HMA mixture [45]. Fig. 6 shows the compaction output with and without zycotherm-SP on HMA and WMA concrete.

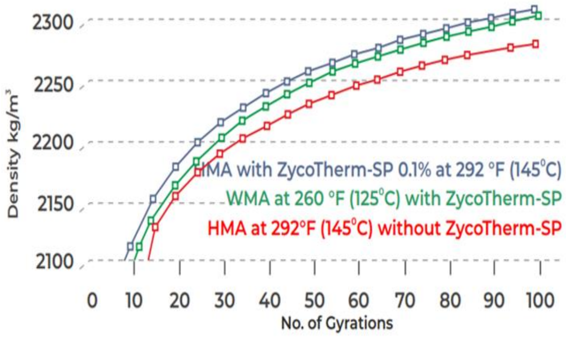

Fig. 6. Compaction output with and without zycotherm-SP on HMA and WMA [31]

III. MATERIALS AND METHODS

Materials used in this study were provided by the Faculty of Civil Engineering, Universiti Teknologi Malaysia, Skudai, Johor Bahru, Malaysia. These materials include bitumen, aggregates (coarse and fine), cement (filler), and ZT-SP2.

Aggregate and binder tests were conducted to determine aggregate and binder characterizations. Aggregate tests conducted in this study comprise aggregate impact value test, Los Angeles Abrasion value test, water absorption test, and specific gravity of coarse and fine aggregates. However, binder tests conducted comprise stability, softening point, penetration, flash and fire point, ductility, viscosity, Marshall stability and flow, ITS, TSR tests, and volumetric analysis. All the tests were conducted in a laboratory setup.

IV. RESULTS AND DISCUSSIONS

A. Binder

Binder characterizations are conducted in a laboratory setup and the results of the experiments are shown in Table 2. Almost all the binder properties have satisfied JKR specification limits.

Table 2. Summary of the results of binder properties using 0.1% ZT-SP2

S/N	Property	Unit	Results	JKR limit	Test method
1	Stability	^{0}C	0.30	-	ASTM D7173
2	Softening point	^{0}C	48	48 - 56	ASTM D36
3	Penetration	mm	67	60 - 70	ASTM D5
4	Flash point	^{0}C	285	230 (min)	ASTM D92
5	Fire point	^{0}C	320	230 (min)	ASTM D92
6	Ductility	cm	109	≥100	ASTM D113
7	Elastic recovery	%	32	-	ASTM D6084
8	Viscosity	Pa.s	0.62	≤3	ASTM D4402
9	ITS	N/mm^2	1.059	-	ASTM D6931
10	TSR	%	89.11	-	ASTM D8467

B. Aggregate

Property of aggregate is the most important parameter for assessing the performance of WMA concrete using ZT-SP2. The results of the aggregate properties are depicted in Table 3.

Table 3. Summary of the results of aggregate properties

S/N	Property	Unit	Results	JKR standard	Test method
1	Los Angeles Abrasion value	%	23	≤25	ASTM C131
2	Aggregate impact value	%	22	<25	BS 812: Part 112
3	Specific gravity:				
	Coarse aggregate	-	2.07	-	AASHTO T85
	Fine aggregate	-	2.18	-	AASHTO T84
4	Specific gravity (combined)	-	2.28	-	AASHTO T84 &T85
5	Water absorption:				
	Coarse aggregate	%	1.22	≤2	AASHTO T85
	Fine aggregate	%	1.75	≤2	AASHTO T84

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C. Indirect Tensile Strength (ITS)

The results of the ITS test of HMA (control sample) and WMA using ZT-SP2, 0.1% are shown in Table 4. The average value of ITS of HMA (1.149 N/mm^2) is greater when compared to WMA (1.057 N/mm^2). Fig. 7 shows the ITS of HMA and WMA mixtures using 0.1% ZT-SP2.

Table 4. ITS of HMA and WMA using ZT-SP2 (0.1%)

No. of test	ITS (N/mm^2)	
	HMA	WMA
1	0.996	0.960
2	1.204	0.988
3	1.246	1.224
Average	**1.149**	**1.057**

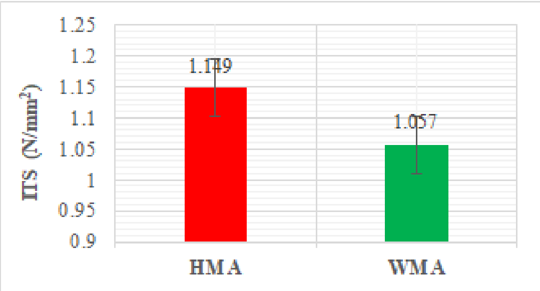

Fig. 7. ITS of HMA and WMA mixtures

D. Tensile Strength Ratio (TSR)

The results of the TSR of the control sample and WMA concrete are shown in Table 5. HMA has the larger average value of TSR (97.62%) when compared to WMA (89.11%). Fig. 8 shows the TSR of HMA and WMA using ZT-SP2 (0.1%).

Table 5. TSR of HMA and WMA using ZT-SP2 (0.1%)

Mixture type	ITS (N/mm^2) Unconditioned	Conditioned at 60^{0}C	TSR (%)
HMA	0.968	0.945	97.62
WMA	1.102	0.982	89.11

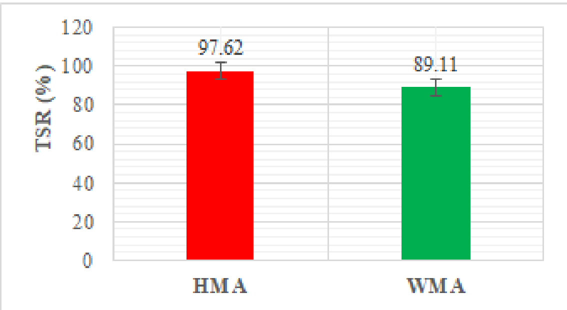

Fig. 8. TSR of HMA and WMA

E. Marshall Properties

The summary of the results of the different Marshall properties of WMA concrete using ZT-SP2, 0.1% is shown in Table 6. The Marshall properties have conformed with the JKR specification limits. Fig. 9 shows the Marshall stability and flow of WMA using ZT-SP2 (0.1%).

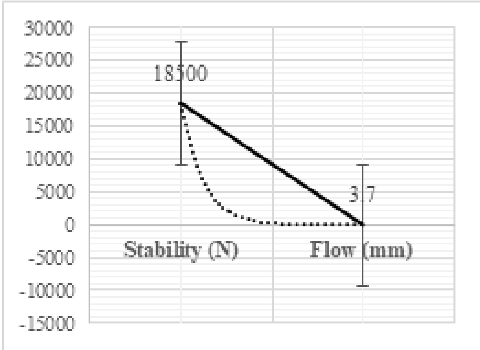

Fig. 9. Marshall stability and flow

Table 6. Summary of the results of Marshall properties of WMA using 0.1% ZT-SP2

S/N	Marshall Property	Unit	Results	JKR standard
1	OBC	%	5.9	5 - 7
2	Stability	N	18500	>13000
3	Flow	mm	3.7	2 - 5
4	Stiffness	N/mm	5000	>2600
5	AV	%	4.7	4 - 6
6	VMA	%	18.2	-
7	VFB	%	74	70 - 80

Legend: OBC is the optimum bitumen content, AV is the air voids, VMA is the voids in mineral aggregate, and VFB is the voids filled with bitumen.

V. CONCLUSION AND RECOMMENDATIONS

The following conclusions were made on the performance of WMA concrete with the integration of ZT-SP2:

- The inclusion of 0.1% ZT-SP2 in WMA-modified concrete facilitates its improved performance and sustained workability.
- The use of several ZycoTherm types has improved the production of WMA pavements by the construction industry. This article provides an overview of the literature on several ZycoTherm additive forms for altering asphalt binders.
- Using WMA technology has several practical, economic, and ecological benefits. Long transit periods for asphalt can be accomplished with WMA technology without sacrificing the product's workability.
- • While WMA concrete has several benefits for structural behavior, it also has self-functional disadvantages, especially when moisture susceptibility is taken into account. Two disadvantages of WMA include the greater vulnerability to moisture and the early rutting of the pavement surface.
- WMA modern technology (incorporation of ZT-SP2)

reduces the softening point but increases the penetration value of the modified bitumen.
- All the tests were made in a laboratory setup.
- The results showed that the use of ZT-SP2 dose of not more than 0.1% enhances the performance of WMA concrete.

Nevertheless, more in-situ research is required to demonstrate ZT-SP2's effectiveness in practical settings. More research utilizing additional warm mix additives is also required to improve the association between ZT-SP2 integration and WMA concrete's structural behavior.

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