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Effectiveness of Liquid Antistripping Agents' Resistance to Moisture Damage of Hot Mix Asphalt

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***Abstract*---- Usage of antistripping additives to improve hot mix asphalt resistance to moisture damage has been studied by many researchers and found to be an effective solution to the design and construction of asphalt pavement susceptible to stripping. The objective of this study is to investigate the moisture resistance of asphalt mixtures modified with liquid antistripping agents in comparison to traditional solid antistripping additives, and to evaluate their cost effectiveness. Bitumen penetration 80-100, aggregate gradation type 4C (according to Egyptian specification), two types of liquid antistripping agents, and two types of traditional solid antistripping agent were used. The liquid agents were Fatty Acid Polyamine (FAP) and Phosphoric Acid-Based anti-stripping agent (PAB). Solid agents were Portland cement and lime. Agents were added at different dosages to evaluate asphalt moisture damage resistance. Boiling water test, Index of retained strength and modified Lottman test have been conducted. Observation and quantification results showed that the liquid antistripping additives had better performance when compared to the solid agents and the control samples. FAP showed an improvement of 30.62% Tensile Strength Ratio (TSR) and 27.2% of retained coated area as compared to the conventional bitumen. The economic analysis also showed that FAP is the most cost effective.**

***Keywords*--- Asphalt, moisture susceptibility, Antistripping additives, cost-effectiveness analysis**

I. INTRODUCTION

Moisture damage is one of the primary modes of asphalt pavement failure. It weakens the adhesion between the aggregate and the asphalt binder, which in turn reduces the structural strength of the asphalt mix. It is also often one of the main factors affecting the durability of the road pavement [1], [2]. Moisture damage in Hot Mix Asphalt (HMA) , which may lead to stripping, may act in three different ways such as: loss of cohesion, loss of adhesion, and aggregate degradation [3], which reduces the service life of the pavement [4]. As a result, it could accelerates or lead to several distresses such as raveling, potholes ,bleeding of the binder to the pavement surface, which could decrease pavement's skid resistance (driver safety) and increase cost of maintenance [5], [6]. Thus, stripping can potentially have an impact on development and resource use in the context of the national economy.

Many African countries face the moisture damage challenge especially in countries with wet weather conditions and or coastal areas. In Egypt like many other countries, Liquid antistripping agents are overlooked, and powder antistripping agents are not often added in the asphalt mixture due to poor workability in adding and mixing processes and some other environmental problems such as dust emission. In addition to that, solid antistripping agents require high quality control. Therefore, roads usually show excessive failures of an early stage of pavement life because of using asphalt mixture without antistripping agents. On highways and urban roads, damaged spots can be seen after the seasonal rains, which may cause stripping due to the properties of local aggregates. Moreover, the severe water damage problems in Egypt are due to the high-water table. The rising of the water table is accelerated due to its huge coastal locations on red and white seas as well as on the River Nile [7].

Moisture damage needs to be addressed in design and construction [8] especially based on its factors which are known to be: aggregate properties (Surface texture, mineralogy, porosity, surface moisture, surface chemical composition and surface coating); bitumen characteristics (Asphalt film thickness, viscosity, physical and chemical structure); construction method (by considering compaction method, drainage system, air void mechanism); environmental condition such as climates, environmental temperature and not to forget traffic load imposed on the pavement [7], [9]. Many researchers have tried a variety of additives that may fight against moisture damage, see Table 1 and they have proved the usage of antistripping agents to be a very effective and popular method for reducing the stripping potential of asphalt mixes.

Antistripping agent dosage rate may varies by agencies,

Some agencies use dosage range of between 0.05% and 0.1% by weight of the bitumen, and others use 0.25% to 0.50% as their common addition rate [10]. However previous engineering practice and laboratory experiments have shown that the binder properties are not significantly affected by the liquid antistripping agents at those common range ratio [11], [12] ; therefore liquid antistripping agent when added to the asphalt binder should not exceed the manufacturer's maximum recommended dosage rate [13].
To provide a solution of pavement moisture damage issues, liquid anti stripping agents were considered for not only to eliminate the moisture sensitivity of the HMA [14], but also to get rid of some environmental and economic problems associated with using traditional solid antistripping (Cement dust and lime stone mineral filler). Liquid antistripping agents have shown their benefits in eliminating of dust emission, improving the workability of the asphalt concrete, permitting better wetting on dry and wet aggregate, allowing the use of a wider selection of aggregates, showing better adhesion of bitumen-aggregates, and using a lower dosage by weight of the bitumen in the HMA [10], [12]. Therefore, the motivation of this study was to address the environmental issues of solid agents.
The objective of this paper is to investigate the performance and cost effectiveness of using liquid antistripping agents for resistance of moisture damage, in comparison to traditional solid agents. To accomplish this objective, a laboratory experimental program was designed and performed to evaluate the improvement in moisture resistance in asphalt mixes using different combinations of solid and liquid antistripping agents. the results of the analysis cover the evaluation of the laboratory testing results and cost effectiveness of using different antistripping agents.

Table 1: Previous findings about antistripping additives

	Additive	Dosage	Bitumen penetration grade	Aggregate NMS (mm)	TSR contr.mix (%)	TSR modified mix (%)	reference
1	Hydrated Lime)	20 %B	60–70	12.5	50	81	[15]
		1%A	PG 64-22	12.5	55	80	[16]
		1.5%A	40-50	19	75.5	94	[17]
			60-70	19	72	93	
		2%A	58	19	88.9	93.5	[14]
2	Lime (CaCO3)	5%B	60–70	12.5	50	80	[15]
3	slaked lime	25%F	85	19	76.4	84.2	[18]
4	Nano-Hydrated Lime	2%B	60–70	12.5	50	81	[15]
5	Nano-lime	2%B	60–70	12.5	50	80	[15]
6	Nano-Clay	2%B	60–70	12.5	50	61	[15]
7	Nano-silica (SiO2)	2%B	60–70	12.5	50	55	[15]
8	steel slag powder (SSP)	25%F	85	19	76.4	79.2	[18]
9	Cement	25%F	85	19	76.4	77	[18]
10	Zycosoil	0.1%B	58	19	88.93	96.4	[14]
		4%B	60-70	12.5	63.5	90	[19]
		4%B	60-70	12.5	58.4	78.3	
11	Zycotherm	0.15%B	40	-	82.73	96.3	[2]
12	Styrene-Butadiene-Styrene	5%B	70-100	12.5	71	82.7	[20]
13	Natural Rubber (NR) latex	4%B	40	-	82.73	87.7	[2]
14	Novolac	2%B	40-50	12.5	63	91	[21]
15	Polyvinyl Alcohol (PVA)	2%B	40-50	12.5	63	77	[21]
16	Ethylene Vinyl Acetate	7%B	47	-	91	96.1	[22]
17	Fly ash	1%A	PG 64-22	12.5	55	70	[16]
18	Cement kiln dust (CKD)	1%A	PG 64-22	12.5	55	78	[16]

NMS: Nominal maximum size
TSR: Indirect Tensile Strength Ratio

%A: Ratio measured by weight of aggregates.
%B: Ratio measured by weight of binder.
%F: Ratio measured by weight of filler

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II. MATERIALS AND METHODOLOGY

The materials used in the experimental program included the bitumen binder, aggregate materials, liquid, and solid antistripping agents. Evaluating impact of liquid anti-stripping additives, lime and Portland cement on HMA resistance to moisture damage was done by running boiling water test ASTM D 3625 on boiled and non-boiled bituminous-coated aggregate mixture, Marshall test and modified Lottman test Referring to AASHTO T283 on conditioned and unconditioned Marshall specimens. From these tests: Image analysis results using ImageJ 1.53e Software, the Index of retained strength (RMS) also named Retained Marshall Stability, Indirect Tensile Strength Ratio (TSR) have been studied to characterize asphalt mix moisture susceptibility and the additives cost effectiveness.

2.1 Bitumen binder and aggregate

The bitumen binder penetration Grade 80/100 has been used; their properties were determined through conventional tests as listed in Table 2 below . The aggregates gradation used in this research is 19 mm nominal maximum size, 4C gradation type according to Egyptian specification, dense gradation (currently most used gradation in Egyptian surface mixes) as shown in Figure 1 below.

Table 2: Properties of asphalt binder.

Properties	Standard	Measured values
Density (g/cm^3)	ASTM D70	1.021
Penetration at 25^{0}C (0.1 mm)	ASTM D5	95
Softening point (^{0}C)	ASTM D36	49
Ductility at 25^{0}C (cm)	ASTM D113	>100
Viscosity at 135^{0}C, cSt	ASTM D2170	295.5

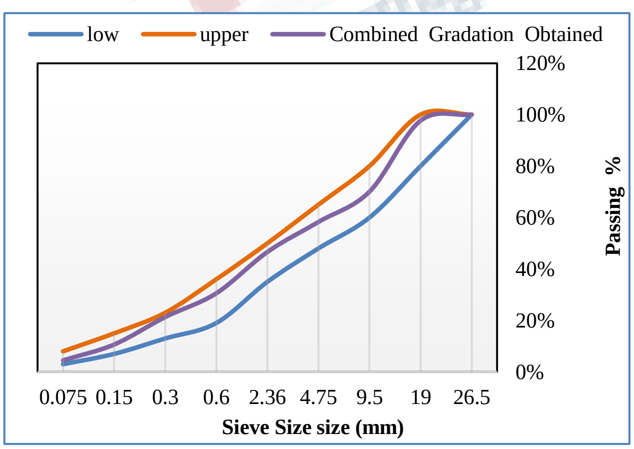

Figure 1: Aggregate's gradation

2.2 Additives

In this study, solid and liquid antistripping agents, with two types of each of the liquid and solid agents, are used at different dosage rate: Solid antistripping agents used are Portland cement and lime, both were used at 2% by weight of the mixture. Liquid antistripping agents used are Fatty Acid Polyamine (FAP) and Phosphoric Acid-Based anti-stripping agent (PAB), their properties are found in Table 3 below.

Table 3: liquid antistripping properties

Properties	PAB	FAP
Aspect viscous	Liquid,	Liquid
Appearance	Brown	clear,
Density at 25°C	0,90 ± 0,1 g/cm3	0.889g/cm3
Viscosity at 25°C	250 ± 100 cP	115 mPas
Flash point	> 150°C	-
pH	Acid	Acid
Active content	-	approx. 100 %

Liquid additives FAP and PAB were chosen due to their availability with affordable price on Egypt local market, they are solvent-free, free of aromatic oils very dangerous to human health, they also stable at the high storage temperatures of the bitumen, they can be dosed either in line during the production cycle of the asphalt concrete (in the mixer or, preferably, in the bitumen scale) or directly into the storage tank, they improve the workability of the asphalt concrete and they use a low dosage.
From the previous studies, It is known that too low dosage of the liquid antistripping agents has no significant affects on the binder properties, and also higher dosage might negatively affect the rheological properties of the binders and potentially cause unexpected degradation of pavement performance.[12]. To know the optimum dosage for each liquid antistripping agent, moisture damage tests were done at different dosage rate 0.15%, 0.25%, 03%, 0.45% and at 0.5% by the weight of mixture.

III. LABORATORY TESTING AND ANALYSIS

The experimental program included performing boiling water test, Marshall test, and indirect tensile test see Table 4. Image analysis is performed using ImageJ 1.53e Software after the boiling test. Analysis of the test results includes the evaluation of the Index of retained strength (RMS) and Indirect Tensile Strength Ratio (TSR) to characterize asphalt mix moisture susceptibility. Cost analysis was also performed to evaluate the cost effectiveness of using the various antistripping agents.

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Table 4: Experimental program and types of mixes used.

Moisture sensitivity tests on loose samples (Boiling water test ASTM D 3625)		PAB 0.5% and FAP 0.3%			
Moisture sensitivity tests on compacted specimens		Retained Marshall test		Indirect tensile strength test	
		unconditioned	conditioned	unconditioned	conditioned
1	Control mix	3	3	3	3
2	PAB 0.5%	3	3	3	3
3	PAB 0.25%	3	3	3	3
4	FAP 0.45%	3	3	3	3
5	FAP 0.3%	3	3	3	3
6	FAP 0.15%	3	3	3	3
7	FAP 0.15%+ PAB 0.25%	3	3	3	3
8	Portland Cement 2%	3	3	3	3
9	Lime 2%	3	3	3	3
		Total samples			108

3.1 Mix design and specimen's preparation.

Marshall test has been conducted as per ASTM Designation D6926 and ASTM D 6927 to determine the optimum binder content of HMA mixtures with the targeted design air void of 4% for all mixtures, and the optimum asphalt content was found to be 5.1%.

3.2 Boiling water test

Boiling test is a qualitative test, which depends on visual observation of the operator [23]. To eliminate this disadvantage, digital color photographs are analyzed to have a more objective evaluation.

The boiling water test was conducted, as per the ASTM D 3625. In order to quantify the amount of moisture damage digital color photographs of the boiled mixtures and a non-boiled mixture were taken with sufficient indirect light to prevent creation of excessive sparkles and saved in JPEG format

According to ASTM D3625, any thin, brownish, translucent areas should be considered fully coated, so aggregate surface exposure, nonblack area, was considered as stripping. After applying the specific threshold level, Image analysis has been able to distinguish the stripping and bituminous-coated aggregate area respectively based on the exposure content of aggregate, as shown in Fig. 2.

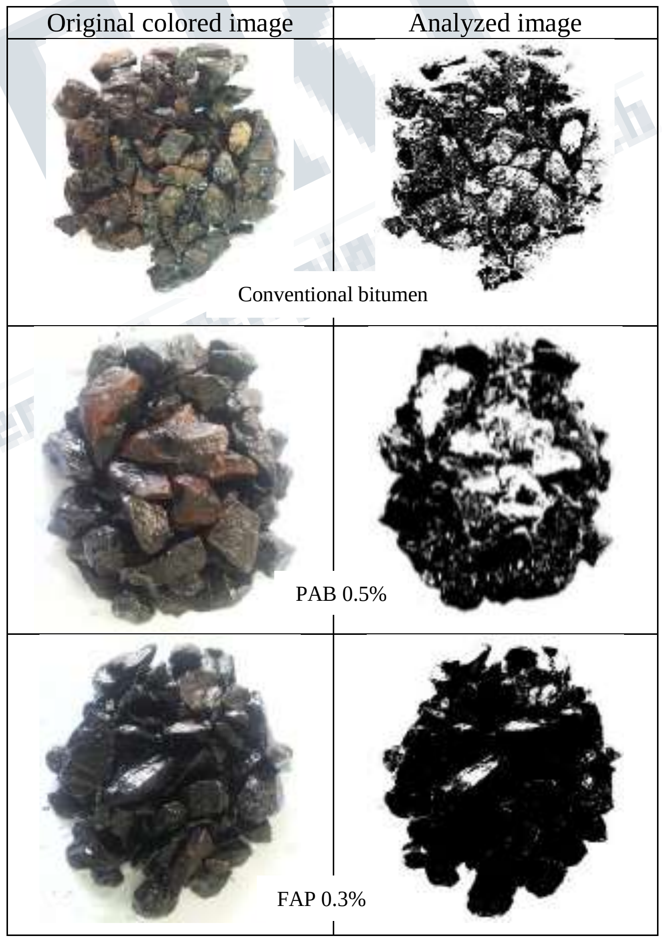

Figure 2: Stripping and Bituminous-coated aggregate area detection

Image analysis technique by ImageJ 1.53e Software was employed. Image were imported into ImageJ software and scaled. Different threshold levels were applied to segment, detect, and separate the background and sparkles [24].
Observation and Image analysis results have shown that both FAP and PAB anti-stripping agent may attenuate the effect of water on HMA mixture. However, FAP agent was more effective in reducing the moisture damage than PAB agent. The retained bituminous-coated area of aggregate mixture with PAB 0.5% and FAP 0.3% anti-stripping agents were 8.93% and 27.2% higher than the conventional mix, respectively, as shown in Fig. 3.

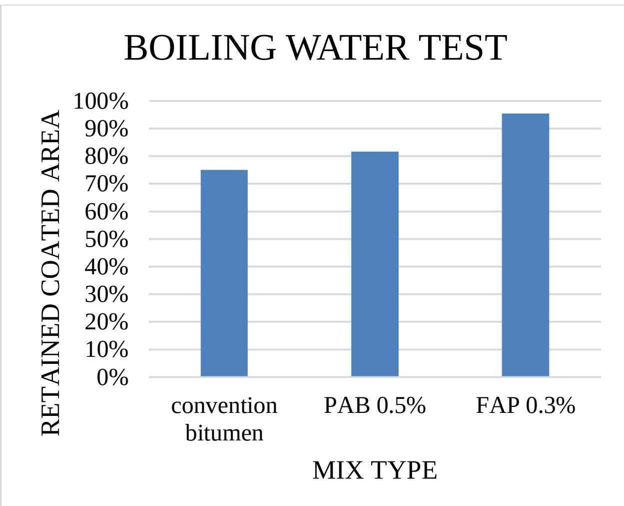

Figure 3: Boiling water test

3.3 Marshall test

Referring to ASTM D1075 and AASHTO T165 and With 5.1% obtained optimum asphalt content, nine different HMA mixtures types have been prepared: Mixture without additive which is considered as control , HMA mixture with 0.45%, 0.3% and 0.15% FAP, HMA mixture with 0.5% and 0.25% PAB anti-stripping agent, HMA mixture with 0.15% FAP + 0.25% PAB anti-stripping agent ratio measured by weight of mixture , HMA mixture with Portland Cement 2% by weight of the mixture and HMA mixture with lime 2% by weight of the mixture. For each HMA mixture type, six specimens have been prepared and divided in two subsets of three specimens. The first subset, unconditioned one, has been tested after being put in water bath 30 minute at 60°C (140°F). Another subset tested after being conditioned 24 hours at 60^{o}C in water bath as it is recommended according to AASHTO T283 except for the freeze cycle. Referring to ASTM D1559, Marshall stability, Marshall flow, Index of Retained Strength (RMS) or Retained Marshall Stability , Retained Stiffness Ratio (EST= Marshall stability/Marshall flow of conditioned and unconditioned mixtures) have been provided by loading the specimen to failure using a computerized Universal Testing Machine (UTM).
Result from the Marshall test, below, led to these facts:

- Mixture with liquid antistripping additives or lime showed a slight change in Marshall flow as compared to unconditioned and conditioned HMA mixtures. Fig. 4
- Control mixture had the least RMS and EST values with comparing to all other specimens. This may explain how the addition of an antistripping additive in HMA may improve the resistance of the mixture to the deformation loading, hence the increase in the rigidity of asphalt mixture. Fig. 5
- The retained stability is used to assess the moisture destruction and to determine the amount of decrease in strength and/or stiffness of HMA [23] but some samples have RMS and EST greater than 100% (Fig.5). This reveals that the retained stability is least affected by moisture conditioning when compared with other moisture susceptibility parameters. This confirming the result found by [25], [26].
- Liquid anti stripping agents have improved mixing workability and they have shown no dust emission.

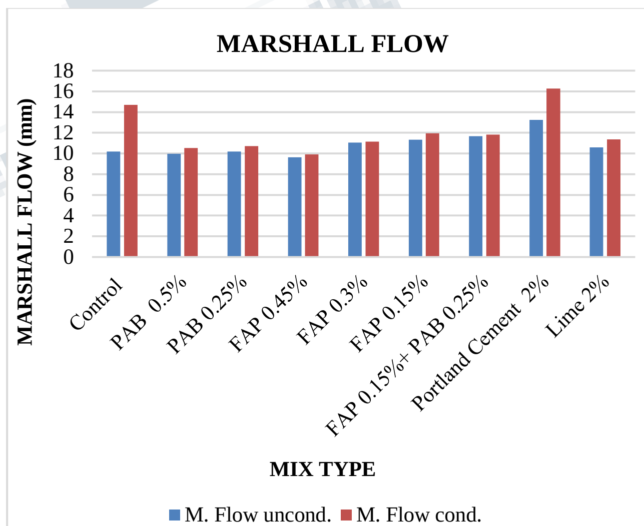

Figure 4: Marshall flow

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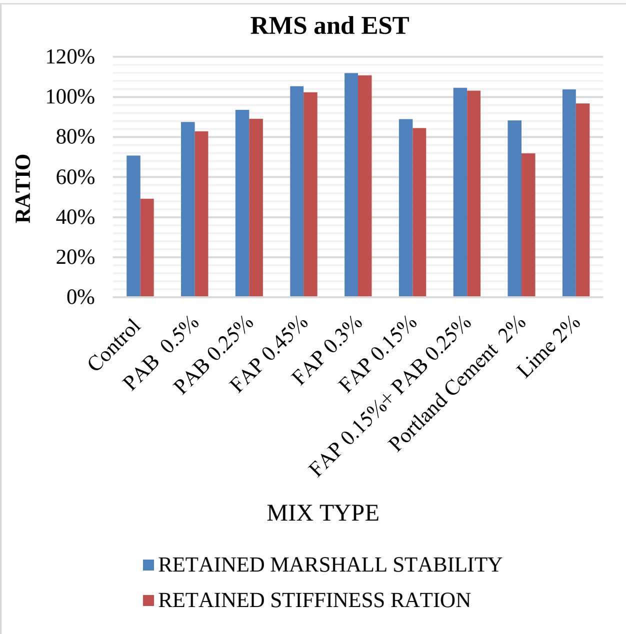
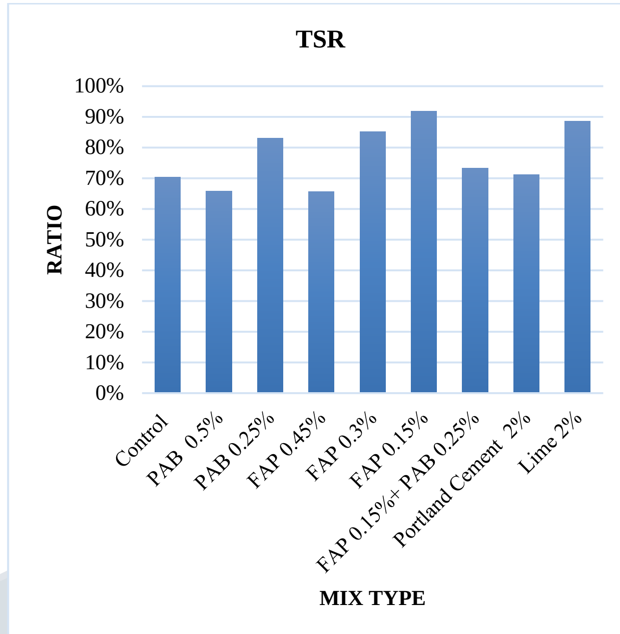
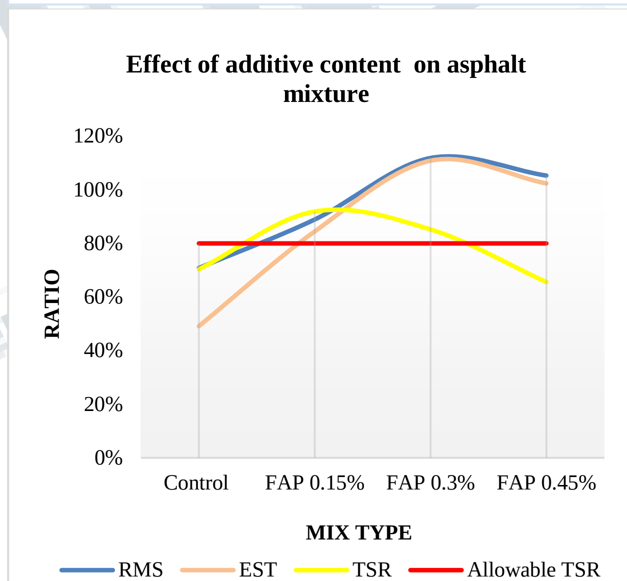


Figure 5: RMS and EST results





3.4 Indirect-tensile strength test.

The same nine HMA mixtures types were prepared as it was done in Retained Marshall test and for each HMA mixture type, six specimens were prepared and divided in two subsets of three specimens each (dry and conditioned). Indirect-tensile strength test was conducted referring to modified Lottman test AASHTO T283.

Results from indirect-tensile strength test showed that:

- Regarding the TSR results (Fig. 6), the additional of liquid anti striping agents or lime in HMA mixtures improved the resistance to moisture damage of the conventional bitumen. PAB 0.25% raised TSR of conventional bitumen by 18.01% and FAP 0.15% by 30.62%TSR while that of HMA containing lime 2% was increased by 26%TSR
- Although the additional of antistripping agent improves the resistance to moisture damage in asphalt mixture (Fig.7), it has the optimum content. Therefore, an antistripping agent content may be chosen in the range which provides allowable TSR (TSR above 80%) depending on the targeted parameter (Retained Marshall, stiffness ratio or tensile strength ratio)
- The same as in Marshall test, liquid anti stripping agents were easy in handling. They have improved mixing workability and they have shown no dust emission.

3.5 Cost effectiveness analysis

Cost analysis was calculated by considering different alternatives and comparing their one-ton metric mixture (1000kg) cost (C) without additive and the one containing additives. Benefit (B) was the improvement of TSR (%). Addition of liquid additive in the mixture affect the binder weight, so aggregate weight can be omitted in the cost estimation (Table 5). The price of material used were found currently from Egypt local market and EGP (Egyptian Pound) is the currency used.

Considering pavement durability (number of years) that

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may be gained from the type of added antistripping agent as a desired benefit would have been better unfortunately, there is a lack of that information. However, many studies have shown that moisture damage is one of the primary modes of asphalt pavement failure, the main factor affecting the durability of the road pavement [1], [25], therefore TSR value was chosen to be the targeted benefit. Public agencies have different acceptable TSR values range between 70% - 80. Referring to Wisconsin, a state of U.S. minimum allowable TSR with no antistripping additive is 75% and 80% with antistripping additive [27], [28]. HMA mixture should satisfy both the TSR specification and cost-effectiveness.
Cost effectiveness analysis (Fig.8) has proven that, the usage of lime or liquid antistripping agents (Both FAP and PAB) are cost effective. FAP 0.15% gave the best result with benefit cost ration of 120.4%. The usage of Portland Cement and a combination of FAP 0.15%+PAB 0.25% anti-stripping agents were found to be non-cost effective although they have exhibited slight increase of TSR.

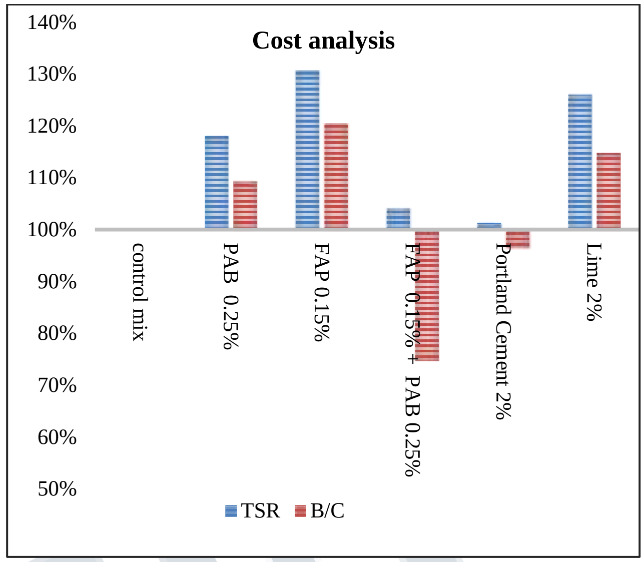

Figure 6: Cost analysis

Table 5: Cost estimation

	bitumen Weight in ton metric mixture (kg)	Additive Weight in ton metric mixture (kg)	bitumen unit price EGP/kg	Additive unit price EGP/kg	Estimated cost for Bitumen in ton metric mix. (EGP)	Estimated cost for Additive in ton metric mix. (EGP)	Mixture estimated cost for ton metric. (EGP) (C)	TSR (%) (B)
Add nothing (control mix)	51	0	12	-	612	0	612	70.35
PAB 0.25%	49.725	1.275	12	50	596.7	63.75	660.45	83.03
FAP 0.15% F	50.235	0.765	12	80	602.82	61.2	664.02	91.90
FAP 0.15% + PAB 0.25%	48.96	2.04	12	130	587.52	265.2	852.72	73.28
Portland Cement 2%	51	20	12	1.5	612	30	642	71.22
Lime 2%	51	20	12	3	612	60	672	88.65

IV. SUMMARY AND CONCLUSION

Handling the Pavement moisture related problems, evaluation of hot mix asphalt resistance to moisture damage was done by comparing the effectiveness of liquid anti-stripping additives and traditional antistripping agent (lime and Portland cement) added in conventional bitumen. It was observed that the addition of an antistripping agent (both liquid and lime) improves the moisture resistance of the asphalt mixture. Moreover, the results showed that liquid antistripping additives had better performance when compared to the solid agents and the control samples. The addition of an antistripping agent should be done with considering its optimum content otherwise the mixture might be more prone to moisture damage than how it was before the addition. Portland cement was found to improve Marshall stability, but it showed little effect in combating moisture damage. Liquid antistripping agent showed the best Tensile Strength Ratio (TSR), where FAP has considerably increased by 30.62% as compared to that of the conventional bitumen. According to boiling test and image analysis, retained

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coated area of mixture with FAP has shown a further improvement of 27.2%. Finally, both lime and liquid antistripping agents were proven to be cost-effective, with the best benefit cost ration of 120.4% for FAP. Furthermore, liquid antistripping agents have a particular advantage over the traditional antistripping agent (lime and Portland cement). liquid antistripping are easier in handling and environmentally friendly. Liquid antistripping agents are also appropriate to the Egyptian mixing brand. The advantages of the investigated liquid antistripping agents would provide a solution on asphalt pavement design and construction. In countries like Egypt, liquid antistripping agents would also be an alternative to solid antistripping agents which are not used due to poor workability in adding and mixing processes, required high quality control and some other environmental problems such as dust emission.

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