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EFFECT OF MOISTURE DAMAGE ON GAP-GRADED ASPHALT MIXTURE INCORPORATING ELECTRIC ARC FURNACE STEEL SLAG AND COPPER MINE TAILINGS

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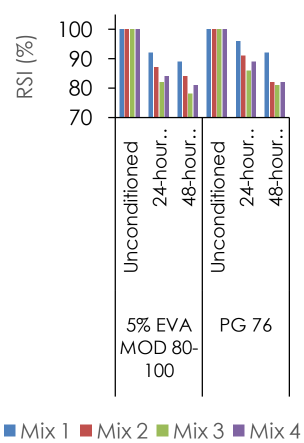
Graphical abstract



Abstract

Water damage is a vital factor affecting the durability of gap-graded asphalt. There is an urgent need for a pragmatic and reasonable test to evaluate this parameter. Previous research has proposed that tensile strength ratio is a promising test for this application. Therefore, the aim of this paper is to evaluate the effect of moisture damage on gap-graded asphalt mixture incorporating electric arc furnace (EAF) steel slag and copper mine tailings (CMT). Four material mixtures of eight mix designs were investigated. Each mix was conditioned in water for 24-hour and 48-hour before testing. The study adopted retained strength index (RSI), durability index (DI) and tensile strength ratio (TSR) to describe the durability of gap-graded asphalt incorporating EAF steel slag and copper mine tailings. The results reveal that all the mixes fulfill the prescribed criteria. Also, there is a strong correlation between the retained strength index and the durability index with a strong coefficient of determination, R^2 of 0.9543. The results of the study further showed that gap-graded asphalt mixture incorporating EAF steel slag and copper mine tailings did not seem to pose any problem.

Keywords: Sustainable technology; copper mine tailings; EAF steel slag; retained strength; durability index

1.0 INTRODUCTION

In the field of construction, road works consume one of the largest proportions of conventional aggregates. However, with the continuously diminishing naturally occurring aggregate, it is highly imperative for highway engineers to start sourcing for alternative aggregates to replace conventional materials like granite [1, 2]. Apart from promoting green technology, it will also enhance environmental sustainability. The use of by-products as replacement for aggregates in hot mix asphalt (HMA)had already started some years ago and the most widely used material for aggregate replacement was either siliceous or calcareous material [3, 4]. Despite numerous advantages, there are also a few challenges in using alternative aggregate materials in the production of HMA. Until now, there have been many studies investigating the use of certain waste materials as aggregate replacement in HMA [5, 6].

In this study, the use of EAF steel slag and CMT as binary material in an asphalt mixture was explored.

EAF steel slag and CMT were used as aggregate replacement to incorporate the enhanced benefits from these materials and also to help in solving the environmental problems commonly associated with other paving materials. By-products like steel slag and tailings were used as aggregate not only to develop superior asphalt mixtures but also to keep them environmentally friendly and reduce the cost of construction [7-9]. Nevertheless, there is still a long way to go before the idea is widely accepted and utilised in the industry. The highway industry is generally slow in accepting new technologies and thus, more research may be needed to prove the superiority of EAF steel slag and CMT over conventional aggregates in their use as pavement material.

Furthermore, in order to understand the adverse effect of action of water on asphalt mixture in which only a few research work has been documented, the specimens used in this study were subjected to various degree of water conditioning. Ali [10], Behiry [11]; Gorkem and Sengoz, [12] conducted an experimental study on the resistance of asphalt concrete against water saturation. The modified immersion method used by the author showed a good understanding to the deterioration of asphalt mixtures durability due to the flood puddle. Other studies that have been carried out focused mainly on the effect of cyclic water vapour to asphalt mixtures. Unfortunately, one of the major treats to the durability of asphalt mixture is infiltration of water into the asphalt pavement [13, 14]. Another vital consequence of the action of water on asphalt mixture is the loss of adhesion between the bitumen and aggregate, generally refer to as stripping, resulting in the reduction of strength of the asphalt mixtures significantly.

In order to study the effect of water damage on gap-graded mixture and at the same time sustaining the policy of green technology and environmental sustainability, this present study has been devoted to assess the influence of water infiltration on SMA 14 mixture incorporated EAF steel slag and copper mine tailings which has not been previously studied.

2.0 MATERIALS AND METHODS

2.1 Raw Materials

The granite aggregate was supplied by UluChoh quarry Johor, Malaysia. The EAF steel slag and copper mine tailings were obtained from Malaysian Marine and Heavy Engineering Company and Antra steel, Malaysia. Both the modified bitumen (PG 76) and conventional bitumen (80-100) was supplied by Shell Ltd, Singapore. The material design which conforms to SMA 14 based on the Malaysian standard specification for road works is illustrated in Table 1 while Figure 1 depicts the gradation curve of the mix. Also, the properties of the aggregates and bitumen binders are listed in Tables 2 and 3 respectively.

Table 1 Gradation limits of the combined aggregates for SMA

Fraction	Percentage Retained by weight							
	Mix 1	Mix 2		Mix 3		Mix 4		
	Granite	Granite	Copper tailing	EAF slag	Copper tailing	Granite	EAF slag	Copper tailing
12.5	0	0	0	0	0	0	0	0
9.5	22	22	0	22	0	11	11	0
4.75	46	46	0	46	0	23	23	0
2.36	13	10	3	10	3	5	5	3
0.60	5	0	5	0	5	0	0	5
0.30	2	0	2	0	2	0	0	2
0.075	4	0	4	0	4	0	0	4
Pan	6	0	6	0	6	0	0	6
Cement	2	2	2	2	2	2	2	2

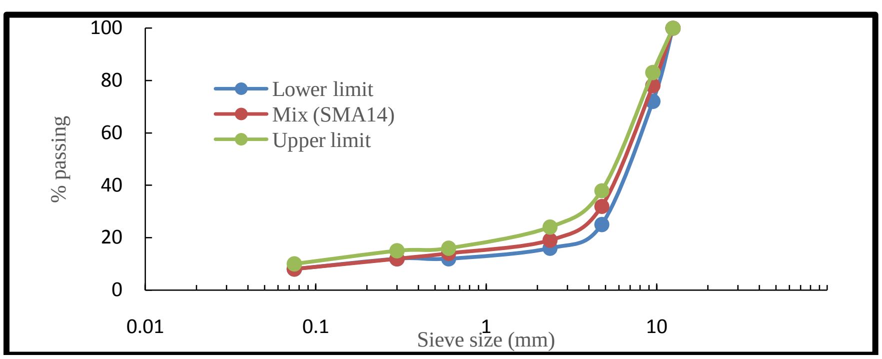


Figure 1 Aggregate gradation for SMA 14

Table 2 Properties of the aggregates

Testing	Specification	Granite	EAF Steel slag	Copper mine tailings	Standard
Loss Angeles Abrasion (%)	≤ 25	10.28	5.10	-	ASTM C 131
Flakiness (%)	≤ 25	7	5	-	BS 812
Soundness (%)	≤ 18	3.5	0.71	-	AASHTO T 104
Polished Stone Value (%)	≥ 40	52.3	55.3	-	BS 812
Water Absorption (%)	≤ 2	0.76	3.90	4.17	MS 30
Adhesion (%)	≥ 9	> 95	> 95	-	AASHTO T 182
Specific gravity:					
Fine Aggregate		2.59	3.05	3.58	ASTM C 127
Coarse Aggregate		2.59	2.82	-	ASTM C 128

Table 3 Properties of bitumen binder

Parameter	5% EVA MOD 80-100	PG 76	Standards
Specific gravity	1.02	1.03	ASTM D70
Softening point	63	64	ASTM D36
Penetration @ 25°C	49	48	ASTM D5
Dynamic viscosity @ 60°C	34.3 Pas	45.7 Pas	ASTM D44
Dynamic viscosity @ 135°C	0.3 Pas	1.4 Pas	ASTM D44
Penetration Index (PI)	1.96	1.96	
Penetration viscosity number	-0.45	-0.47	

2.2 Marshall Test

The test was performed in accordance with ASTM D 5581 [15].Prior to the test, a certain quantity of the aggregates having the designed gradation is dried at a temperature of 105 °C ±5 °C until a constant weight is obtained. The mixing temperature of this test was set at a temperature that produces a kinematic viscosity of 170 ±20 centipoise. The compacting temperature used was the corresponding temperature that produces a kinematic viscosity of 280 ±30 centipoise. The test specimens were prepared for a range of asphalt contents within the prescribed limits.

Thereafter, using the Marshall harmer, the specimens containing the appropriate quantities of aggregates and binder were prepared by mixing and compacting each mixture thoroughly at 50 blows per face. The bulk specific gravity and the maximum theoretical specific gravity of the mix were then determined. The bulk specific gravity was determined by weighing the sample in air and in water. The maximum theoretical specific gravity of the mix was measured for each binder content.

Subsequently, the prepared Marshall specimens were immersed in a water bath maintained at a temperature of 60 ±1 °C for a period of 30 to 40 minutes. The specimens were later tested on a Marshall stability testing machine. The total load (in Newton) that causes failure of the specimen at 60 °C is recorded the Marshall stability value of the specimen. The total amount of deformation that occurs up to the point the load starts decreasing is recorded as the flow value. The laboratory-measured values were then used for a Marshall volumetric analysis. The bulk specific gravity, Void filled with asphalt (VFA), stability and flow test values corresponding to the optimum binder content (OBC) were then obtained to get the values of each mix property.

In addition, the Marshall test was also performed on the wet samples that were initially soaked for 24 hours and 48 hours at 60 °C in order to assess the effect of flood puddle and water damage on the samples. Thereafter, the retaining strength index value was calculated by using equation 1 below;

$$RSI = \frac{M_2}{M_1} X100\% \quad (1)$$

Where M_2 and M_1 are the Marshall stability (in Newton) after immersion for 24 and 48 hours respectively

2.3 Abrasion Test

A Cantabro abrasion test was performed on both the dry and wet samples in accordance with the Malaysian Standard Specificationfor Road Works (JKR)[16]. The test was carried out basically to measure the resistance of the proposed mix to stone loss at high frequency. The specimens were prepared at optimum binder content using Marshall mix design. Also, the wet samples were divided into two sets; one set was soaked for 24 hours while the other set was soaked for 48 hours at ambient temperature.

Thereafter, the specimens were placed in ambient temperature for 48 hours. Prior to testing, the specimens were conditioned at a temperature of 25 °C for at least 6 hours. Each specimen was later put into a Los Angeles Abrasion machine without steel balls and subjected to 300 revolutions at a speed of

30 revolutions per minute (rpm). The abrasion loss of each specimen was computed using equation 2;

$$L = \frac{M_0 - M_1}{M_0 \times 100} \quad (2)$$

Where,
L = Abrasion loss, %
Mo = Initial weight of specimen, g
M_1 = Weight of specimen after 300 revolutions

Furthermore, the durability index was computed using equation 3 below;

$$DI = \frac{S_2}{S_1} \quad (3)$$

where S_2 and S_1 are the mass loss after immersion for 24 and 48 hours respectively.

2.4 Indirect Tensile Strength Test

The test is designed to evaluate the tensile strength properties. The test is performed on Marshall samples having percentage air voids of 7 ±1%. The high percentage of air voids was allowed to expedite the moisture damage of the specimens. The test was conducted following the AASHTO T 283 [17] procedure by subjecting the cylindrical-shaped specimens to compressive loading acting parallel to vertical diametrical plane using Marshall testing equipment. The samples normally fail by splitting along the loaded plane. The specimens were divided into two sets; one set is unconditioned while the other set is conditioned. The condition specimen is subjected to vacuum saturation until it reaches 55-80% saturation level. Consequently, the specimens were wrapped with plastic film and conditioned in a freezer at a temperature of 17 ±1 °C for a period of approximately 17 hours and thereafter submerging in a water bath at 60 °C for 24 hr. The samples were then positioned in a water bath at 25 °C for 120 minutes before testing. The unconditioned samples are put in a water bath at 25 °C for 120 minutes and subsequently subjecting to failure. Based on the load carried by the sample till the point of failure, the indirect tensile strength is calculated by the equation 4 below;

$$ITS = 2P\pi dt \quad (4)$$

The tensile strength ratio is subsequently calculated by equation 5 below;

$$TSR = \frac{ITS_{conditioned}}{ITS_{unconditioned}} \quad (5)$$

where P = maximum load in kN, d= specimen diameter in cm, t= specimen thickness in cm

3.0 RESULTS AND DISCUSSION

3.1 Retained Strength Index

Table 4 depicts the Marshall test results for SMA 14 samples. The 5% EVA modified 80-100 bitumen mixtures report higher OBC than PG 76 mixes. Also, all the mixes except Mix 1 recorded higher Marshall stability for EVA modified 80-100 samples. There is not much of a significant difference in the flow. In addition, the mixes containing either EAF steel slag or copper mine tailings have slightly higher OBC contents than the control mix (Mix 1). Interestingly, Mix 3, which consists of EAF steel slag and copper mine tailings aggregates only, has the highest value of Marshall stability and specific gravity while Mix 1 which is made up of only granite aggregate has the least. In terms of flow, Mix 1 has the highest value and Mix 3 recorded the least value.

In general, the OBC values for the mixes containing either EAF steel slag or copper mine tailings were higher. This can be attributed to the higher porosity of EAF steel slag and copper mine tailings aggregate compared to granite. In terms of performance of the four mixes, Mix 2, 3 and 4 exhibit better Marshall properties than the control mix (Mix 1). The higher angle of internal friction and angularity possessed by EAF steel slag and copper mine tailings improved better aggregate cohesion in the mixes.

The retained strength index (RSI) for all the mixes is displayed in Figure 2. The values represent the average of three specimens. As expected, the value of Marshall stability decreases after moisture conditioning. This is because water serves as a threat to the structural integrity of the binder aggregate interface. Water can attack the adhesive bond between the aggregate and the binder, thus causing stripping. Besides, water can also weaken the binder's stiffness and strength. Hence, water is one of the major factors that reduce the strength of pavement.

It is seen in Figure 2 that the RSI decreases as the period of immersion increases. This implies that the longer the immersion period the more damage is being done by water. Also, due to the high porosity of EAF steel slag and copper mine tailings, the Marshall stability of the conditioned Mixes 2, 3, and 4 samples were lower compared to the control samples but none of the samples has RSI value below 75%, which is the stipulated minimum value of RSI.

However, the effect of water damage on the Marshall stability of gap-graded asphalt was further analysed statistically. An independent t-test analysis was performed to statistically compare the superiority of the mixes. The null hypothesis is that the mean Marshall stability for conditioned and unconditioned mixes is equal. The Levene's Test for Equality of variances shown in Table 5 yields a p-value of 0.002, which means that the difference between the variances is statistically insignificant at 0.05 level of significance. Thus the assumption of equality of variances holds. The p-value 0.002 for the test statistic t (less than 0.05) indicates that there is a significant difference between the Marshall stability for the conditioned and unconditioned samples. Thus, at 5% level of significance, there is strong evidence from the sample data to support the claim that the Marshall stability from the conditioned and unconditioned samples is significantly different.

3.2 Durability Index

The outcome of the durability index of all the control and conditioned samples is presented in Figure 3. The results indicate that the abrasion loss is increasing with the period of abrasion. In addition to that, the samples prepared with 5% EVA modified 80-100 recorded a lower abrasion loss than the PG 76 samples. This trend is expected because EVA modifier improves the temperature susceptibility of the samples, thus enhancing the adhesion of the aggregates and binder. In addition to this, it is observed that asphalt mix samples incorporating EAF steel slag and copper mine tailings exhibited lower abrasion loss than the control samples. Obviously, the EAF steel slag and copper mine tailings had a significant effect on the abrasion loss of gap-graded asphalt. The shape and porosity of EAF steel slag and copper mine tailings strengthen the adhesion and cohesion bond between the aggregates and binder [18-20]. Also, it was clearly observed that the wet samples recorded higher abrasion loss than the dry samples. This is expected because the water tends to weaken the adhesion and cohesion bonds between the aggregates and bitumen binder, thus, contributing to high abrasion loss.

However, the effect of moisture damage on abrasion loss of SMA 14 incorporating EAF steel slag and copper mine tailings was further analysed statistically using one-way ANOVA as listed in Table 6. The results of the independent samples t-test showed that both the 24-hour and 48-hour conditioning significantly affected the value of abrasion loss of the samples. The one-way ANOVA also revealed that 5% EVA modified binder samples yielded lower abrasion loss than the PG 76 sample

Table 4 The Marshall test results for SMA 14

Property	Mix 1		Mix 2		Mix 3		Mix 4	
	MOD 80-100	PG 76	MOD 80-100	PG 76	MOD 80-100	PG 76	MOD 80- 100	PG 76
O.B.C (%)	6.175	5.49	6.20	5.69	6.40	5.84	6.35	5.90
VTM (%)	4.07	4.14	4.19	4.26	4.24	4.49	4.20	4.38
Bulk specific gravity	2.297	2.342	2.394	2.359	2.605	2.601	2.437	2.508
Marshall stability (kN)	11.47	13.80	15.05	13.72	17.49	15.11	15.66	14.00
Flow (mm)	3.43	2.99	3.15	3.13	2.85	2.89	2.91	3.09
M_Q (kN/mm)	3.344	4.615	4.777	4.378	6.136	5.228	5.381	4.550
VMA	17.3	17.1	17.4	17.2	18.1	17.5	17.6	17.3

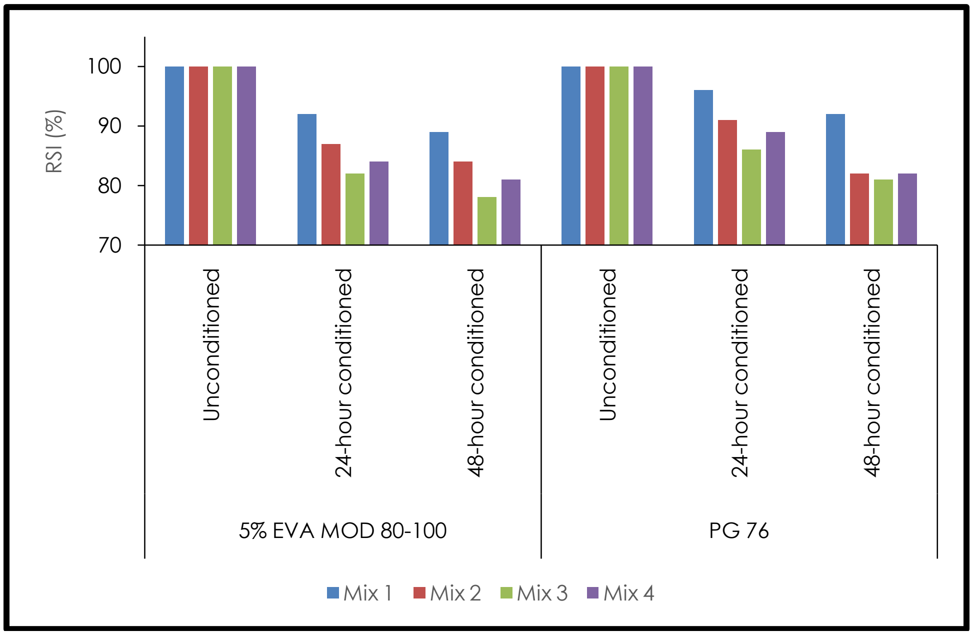


Figure 2 Retained strength index of the mixes

Table 5 The Independent-Samples t-test for Marshall stability

			Marshall stability (Conditioned vs. Unconditioned)	
			Equal variances assumed	Equal variances not assumed
Levene's Test for Equality of Variances	F		54.192	
	Sig.		0.002	
t-test for equality of means	t		7.157	7.157
	df		603.2	466.16
	Sig (2-tailed)		0.002	0.002
	Mean difference		2069.920	2069.920
	Std Error Difference		610.047	610.047
	95% confidence interval of the mean	Lower	869.176	869.176
		Upper	3270.678	3270.678

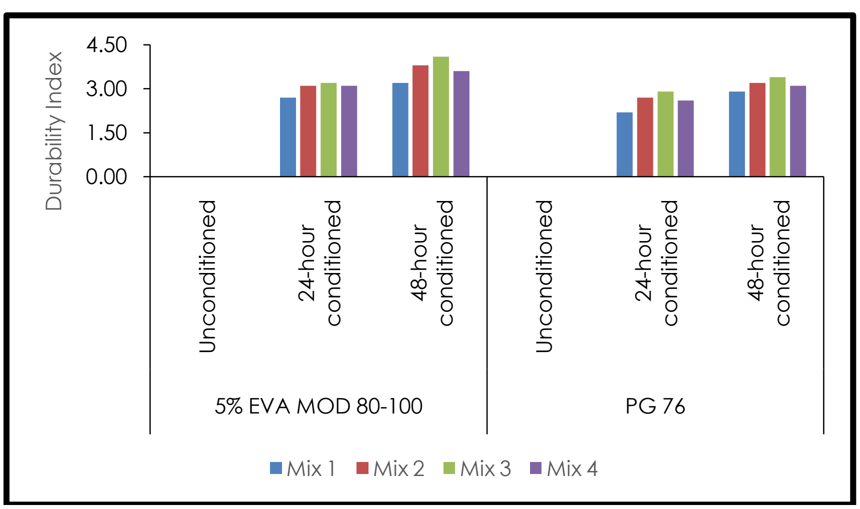


Figure 3 Durability index of the mixes

Table 6 One way ANOVA on the effects of water damaged and binder type on the Abrasion loss

		Sum of Squares	df	Mean Square	F	Sig.
	Between Groups	250135.433	1	250135.433	44.424	.002
24-hr conditioned	Within Groups	371540.524	46	7713.958		
	Total	621675.957	47			
	Between Groups	105609.696	1	118662.579	68.352	.001
48-hr Conditioned	Within Groups	796948.451	46	19466.255		
	Total	902558.147	47			
	Between groups	18521.566	1	17995.243	20.890	0.009
Binder type	Within Groups	46896.432	46	1180.195		
	Total	65417.997	47			

3.2 Tensile Strength Ratio

Figure 4 compares the TSR values of the unconditioned and the conditioned samples at various degree of moisture damaged. It can be observed that Mix 1 has the highest value of 93%, 91%, and 86% respectively for the control, 24-hour and 48-hour conditioning for 5% EVA mod 80-100 samples respectively, whereas the least value of Mix 3 of 79% was recorded at 48-hour conditioning which nearly fulfills the prescribed criteria of 80% recommended by AASHTO T283 [17]. The results indicate that all the samples met the prescribed criteria of 80% except the Mix 3 blended with PG 76 and conditioned for a period of 48 hours. Mixes prepared with EAF steel slag and copper mine tailings have lower TSR values than the control samples. This trend can be attributed to the presence of more pores in EAF steel slag and copper mine tailings. These pores provide adequate vacuum for water absorption in their mixtures. Thus, when ice forms within the pores, it may results in cracking. This finding is similar to that of Wu [21] who reported that SMA mixes tend to exhibit less resistance to moisture damage than AC mixtures due to more voids in SMA mixtures.

The results obtained from the Marshall test and Abrasion test were analysed to determine any possible correlation between the two tests. In Figure 5, a line of linear regression indicated a strong correlation between the retained strength index and the durability index with a strong coefficient of determination, R^2 of 0.9543. This implies that the retained strength index obtained from the Marshall stability test is a reliable test to determine the moisture susceptibility of the mix incorporating EAF steel slag and copper mine tailings.

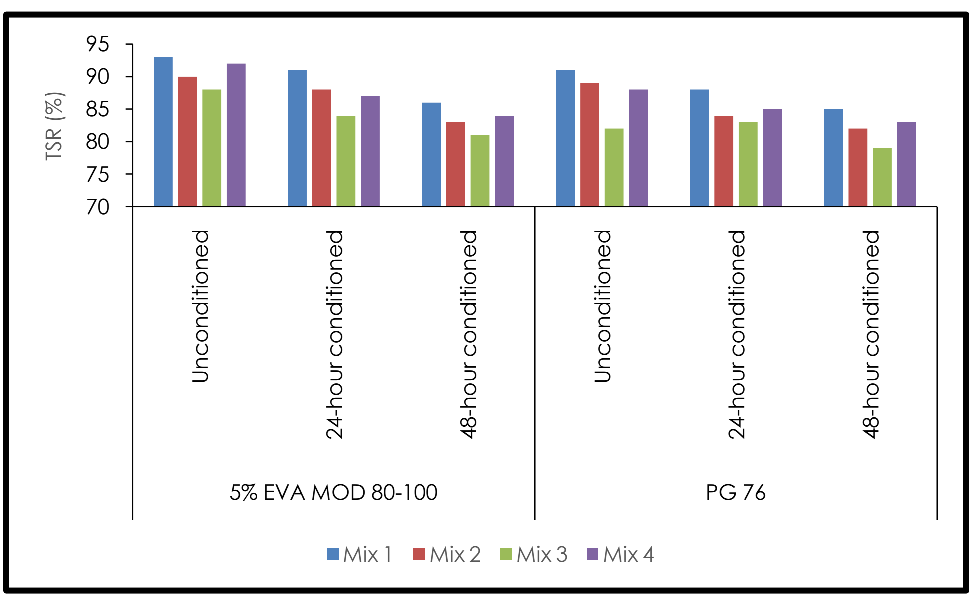


Figure 4 Tensile strength ratio of the mixes

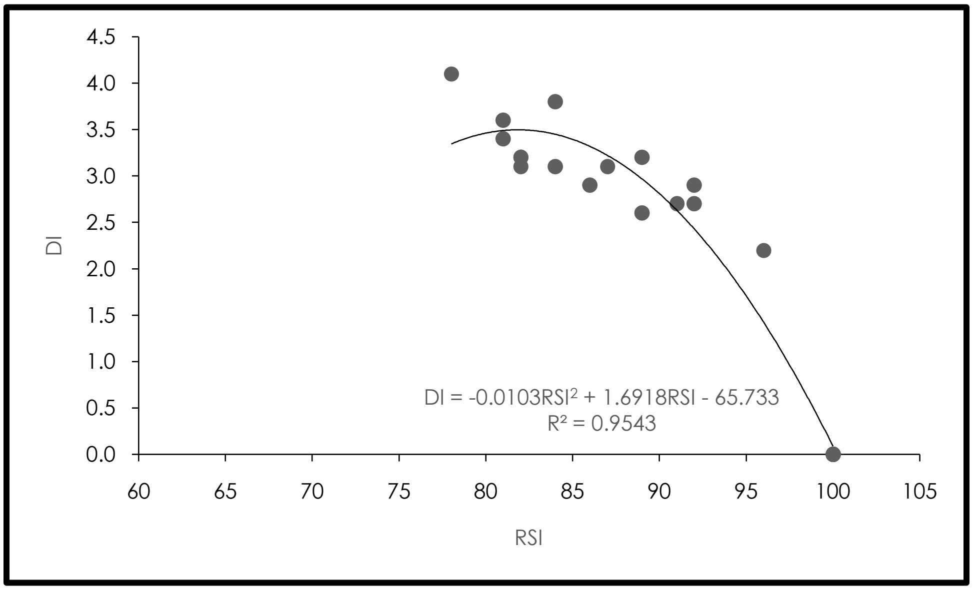


Figure 5 Correlation between the DI and RSI of the mixes

4.0 CONCLUSION

In this paper, attempts have been made to study the effect of water damage on gap-graded asphalt mixture incorporating EAF steel slag and copper mine tailings. The study adopted the concept of durability index in order to understand the influence of water damage on the durability of asphalt mixture. The findings of the study show that the retained strength index values decreases as the conditioning period increases but none of the samples has RSI value below 75%, which is the stipulated minimum value of RSI. In addition to that, there is a significant difference between the Marshall stability of the conditioned and unconditioned samples. In terms of abrasion loss, the wet samples recorded higher abrasion loss than the dry samples. This is expected because the water tends to weaken the adhesion and cohesion bonds between the aggregates and bitumen binder, thus, contributing to high abrasion loss. Due to a strong correlation between the retained strength index and the durability index, the retained strength index obtained from the Marshall stability test is a reliable test to determine the moisture susceptibility of the asphalt mix incorporating EAF steel slag and copper mine tailings.

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References

[1] Hill, A. R., Dawson, A. R. and Mundy, M. 2001. Utilisation of Aggregate Materials In Road Construction And Bulk Fill. *Resources, Conservation and Recycling*. 32: 305-320.

[2] Sherwood, P. T.1995. *Alternative Materials In Road Construction.*Thomas Telford Ltd.

[3] Shen, D. H., Wu, C. M. and Du, J. C. 2008. Performance Evaluation Of Porous Asphalt With Granulated Synthetic Lightweight Aggregate. *Construction and Building Materials*. 22: 902-910.

[4] Ahmedzade, P. and Sengoz, B. 2009. Evaluation of Steel Slag Coarse Aggregate In Hot Mix Asphalt Concrete. *Journal of Hazardous Materials*. 165: 300-305.

[5] Copeland, A. 201. *Reclaimed Asphalt Pavement In Asphalt Mixtures: State Of The Practice* (*No. FHWA-HRT-11-021*).

[6] Silva, H. M., Oliveira, J. R. and Jesus, C. M. 2012. Are Totally Recycled Hot Mix Asphalts A Sustainable Alternative For Road Paving. *Resources, Conservation and Recycling*. 60: 38-48.

[7] Oluwasola, E. A., Hainin, M. R., Aziz, M. M. A., Yaacob, H. and Warid, M. N. M. 2014. Potentials of Steel Slag And Copper Mine Tailings As Construction Materials. *Materials Research Innovations*. 18(S6): 250-254.

[8] Abreu, L. P., Oliveira, J. R., Silva, H. M. and Fonseca, P. V. 2015. Recycled Asphalt Mixtures Produced With High Percentage Of Different Waste Materials. *Construction and Building Materials*. 84: 230-238.

[9] Gómez-Meijide, B., Pérez, I. and Pasandín, A. R. 2015. Recycled Construction And Demolition Waste In Cold Asphalt Mixtures: Evolutionary Properties. *Journal of Cleaner Production*.Volume 112, Part 1: 588-598.

[10] Ali, N. 2013. The Experimental Study on the Resistance of Asphalt Concrete with Butonic Bitumen against Water Saturation.

[11] Behiry, A. E. A. E. M. 2013. Laboratory Evaluation Of Resistance To Moisture Damage In Asphalt Mixtures. *Ain Shams Engineering Journal*. 4: 351-363.

[12] Gorkem, C. and Sengoz, B. 2009. Predicting Stripping And Moisture Induced Damage Of Asphalt Concrete Prepared With Polymer Modified Bitumen And Hydrated Lime. *Construction and Building Materials*. 23: 2227-2236.

[13] Kakar, M. R., Hamzah, M. O. and Valentin, J. 2015. A Review On Moisture Damages Of Hot And Warm Mix Asphalt And Related Investigations. *Journal of Cleaner Production*. 99: 39-58.

[14] Varveri, A., Zhu, J. and Kringos, N. 2015. Moisture Damage In Asphaltic Mixtures.

[15] American Society for Testing Materials. 2013. ASTM D5581. *Standard Test Method for Marshall Stability and Flow Bituminous Mixtures*. Philadephia U.S.: ASTM International.

[16] JabatanKerja Raya Malaysia. Standard Specification for Road Works, Section 4: *Flexible Pavement. No.JKR/SPJ/2008.* S4: S4-58-S4-69.

[17] American Association of State Highway and Transportation Officials. 2007. AASHTO T 283. *Standard Method For Test For Resistance Of Compacted Asphalt Mixtures To Moisture-Induced Damage*.

[18] Oluwasola, E. A., Hainin, M. R. and Aziz, M. M. A. 2015. Evaluation of Asphalt Mixtures Incorporating Electric Arc Furnace Steel Slag And Copper Mine Tailings For Road Construction. *Transportation Geotechnics*. 2: 47-55.

[19] Oluwasola, E.A., Hainin,M.R. and M. M. A.2014. Characteristics and Utilization of Steel Slag in Road Construction, JurnalTeknologi, 70(7): 117-123.

[20] Hainin, M.R., Matori, M.Y and Oluwasola, E.A. 2014. Evaluation of Factors Influencing Strength of Foamed Bitumen Stabilised Mix, JurnalTeknologi. 70(4): 111-119.

[21] Wu, C., Huang, K. and Zeng, M. 2009. Significance Evaluation of Material And Additive Factors Influencing Moisture Susceptibility Of Asphalt Mixtures. *Journal of Testing and Evaluation*. *37*: 1-7.