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The Use of Plastic Fiber for Minimizing Stripping Potential of Bituminous Mixture

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Abstract: One of the effects of water in bituminous pavement is the stripping of aggregates from the mixture causing severe distresses such as potholes. In this study, fiber was produced using recycle plastics and it was used as reinforcement in bituminous mixture against moisture damage. The reinforcements were 0.3%, 0.5% 0.7% and 1.0% of the total weight of bituminous mixture with a view to determine the effective fiber dosage. The stripping potential of control and fiber reinforced mixtures were determined using moisture susceptibility test. From the test results, highest tensile strength ratio (TSR) was obtained in mixtures containing 0.5% recycle plastic fiber. The result also indicated higher indirect tensile strength for both dry and saturated at 0.5% plastic fiber reinforcement. For 0.7% and 1.0% recycle plastic fiber reinforced bituminous mixture, both tensile strength and tensile strength ratio were low compared to that of control mixture. From this study, reinforcing bituminous mixture using 0.5% recycle plastic proved to be effective in improving stripping resistance.

Keywords: Stripping, moisture damage, recycle plastic, fiber, reinforcement, bituminous mixture

1. Introduction

Bituminous mixture is the most currently used material for surfacing of road known as flexible pavements. When water penetrates into flexible pavement, it tends to undermine the pavement strength by weakening the bond between aggregates and bitumen causing stripping. Stripping is among the major source of distress on flexible pavement especially in the high rainfall regions. When moisture damage is occurred, the mechanical properties of bituminous pavement are altered and gradually other failures such as shoving, rutting and cracking may occur [1]. Water in midst of asphalt concrete do results in adhesion failure at aggregate-binder interface, it also distract the cohesion within filler-binder mastic [2].

Water tend to diffuses in to the pavement across bitumen films and affect the partially coated aggregates. The resulted moisture damage may occur as mechanisms such as pore pressure, hydraulic scour, spontaneous emulsification, displacement and detachment [3]. Although traffic loading, moisture and other environmental factors are blamed to be responsible for moisture damage, the quality of paving mixture is also a determinant of the failure [4].

In asphalt concrete technology, moisture susceptibility is determined using Tensile Strength Ratio (TSR). Dry and Saturated tensile strengths of mixtures are determined and the ratio of saturated tensile strength to dry tensile strength is expressed in percentage as TSR value. A minimum value of 80% is considered acceptable.

To minimize the effect of water in flexible pavement, researchers and engineers introduced the use of fiber. Herraiz [5] investigated the use of polyester, hemp and posidonia oceanica fibers in strength improvement of bituminous mixture, he concluded that addition of fiber have improved the moisture susceptibility of the bituminous mixes. Anurag et al. [6] used waste polyester fiber to improve the indirect tensile strength of bituminous mixes. Their result indicated an improvement of water damage resistance in the polyester reinforced mixes. Xue and Qian [7] evaluated the performance of mineral fiber in epoxy asphalt concrete. They concluded that in addition to improved reveling resistance and low temperature cracking, mineral fiber has improved moisture damage resistance by 98%. From literature most of the fibers used in reinforcement of bituminous mixture are synthetic fibers, therefore there is the need to use recycle fiber.

On the other hand, global plastic waste generation is at high rate. A report by Plasticseurope [8] for 2014/2015 affirms that about 299 million tons of plastic was produced in 2013 globally, out of which 59 million tons were produced and mostly used in Europe. However, due to high technology and relatively good environmental regulations in Europe, about 62% of plastic waste generated goes to either recycling or used for energy recovery leaving only 38% for landfills [8].

Meanwhile, unlike in Europe World Bank review on global solid waste [9] reports that, more than 80% of solid waste produced in low and middle income countries end up in landfills [9]. The percentage of plastic in the solid waste is 20-30% by volume [10]. Additionally, 60% of plastics in municipal waste are Polyethylene Terephthalate (PET) bottles[11]. Therefore, it is necessary to develop a simple means of recycling this waste[12].

To improve the performance of asphalt mixture against moisture damage and to reduce plastic waste, recycled PET bottles were used to produce PET fiber that was incorporated into asphalt concrete mixtures.

2. Materials

The materials used are aggregates, bitumen and recycle plastic fiber. Quality test was performed on the materials, the results are presented in tables 1, 2 and 3 for bitumen, aggregates and plastic fiber respectively. Using maximum aggregates size (NMAS) of 12.5mm, the asphalt mixture was designed based on Superpave system. The volumetric property of the designed mixture is presented in Table 4. The waste plastic bottle used for the production of plastic fiber was made from Polyethylene terephthalate (PET). PET is a ubiquitous thermoplastic polymer used for daily household objects. Due to its significant water and moisture resistance, it is used soft drink bottles. It possesses shear strength and thermal resistance even if its subjected to175°C[13]. Fig. 1 shows a plastic fiber used in this study.

Table 1: Properties of bitumen used in this research

Test	Method	Value	Specification
Penetration (dmm)	ASTM D5-97	83	80 - 100
Softening point (°C)	ASTM D36	43	45 - 52
Flash point (°C)	ASTM D92-5	259	Min 232
Ductility (cm)	ASTM D113-99	>100	Min 100

Table 2: Properties of aggregates used in this research

Property	Method	Value (%)	Requirement (%)
Flakiness Index	BS-812-105-1	15	<20
Elongation Index	BS-812-105-2	17	<20
Aggregates Impact Value	BS-812-112	21	<30
Aggregates Crushing Value	BS-812-110	21	<30
Fine Aggregates Angularity	AASHTO T304	49.5	Min 45
sand Equivalent	AASHTO T176	51.3	MIN 45

Table 3: Properties of recycle plastic fiber

Property	Method	Value
Tensile strength (MPa)	ASTM C1557	192.4
Stiffness (N/m)	ASTM C1557	27693
Young's Modulus (MPa)	ASTM C1557	3924.2
Elongation at Break (%)	ASTM C1557	34.2
Water absorption (%)	ASTM D570	0.2
Specific gravity (g/cm3)	ASTM D792	1.356

Table 4: Volumetric properties of designed mixture

Property	Value (%)	Criteria (%)
Air void	4	4
VMA	16	Minimum of 13
VFA	75	65-76
Bitumen content	4.7	4 – 11

3. Methods

3.1 Moisture Susceptibility Test

Moisture susceptibility test was conducted on both control and recycle plastic fiber reinforced mixtures. The test method used was AASHTO T283[14] popularly known as modified Lottman test, the method uses tensile strength ratio (TSR) to evaluate moisture susceptibility of asphalt concrete mixture. The samples were produced at 7±0.5% air voids using the respective optimum bitumen contents of control and reinforced asphalt mixtures.

Fig. 1 Recycle plastic fiber

The dry sub set was tested after two hours curing at 25^{o}C. The wet sub set was saturated and cured in water at 60^{o}C for 24 hours, then cured in water at 25^{o}C and finally tested at 25^{o}C.

3.2 Data Analysis

Response surface methodology (RSM) was used for the data analysis in this studies, RSM is a new approach accepted for analysis in pavement engineering[4, 15-17]. RSM is a statistical tool used for predicting the relationship between factors and responses and also in the analysis of problems[18], it also provide a maximum process performance using designed experiments, historic data and polynomial equations[18].

Using Design Expert 7.0 software, recycle plastic fiber percentage and temperature were used as factors while dry indirect tensile strength (ITS dry), saturated tensile strength (ITS saturated) and tensile strength ratio (TSR) were used as responses were analyzed at 15 runs using historic data as shown in Table 5. To estimate the response variable, a Montgomery quadratic polynomial regression equation was used for four independent variables as shown in equation 1[18]. After the RSM analysis, pictorial surface plots and ANOVA were produced depicting the effect of temperature and percentage addition of plastic fiber on the bituminous mixtures.

$$Y = b_0 + \sum_{i=1}^{n} b_i x_i + \sum_{i=1}^{n} b_{ij} x_i^2 + \sum_{i=1}^{n} \sum_{j=1}^{n} b_{ij} x_i x_j + \varepsilon \quad (1)$$

In Eq. 1, Y is the response variable, n is the number of factors, ε is random error, b_0, b_i, b_{ii} and b_{ij} are constant coefficients of intercept, linear, quadratic and interaction terms (independent variables] respectively.

4. Results and Discussion

Table 5 is RSM experimental design layout for historic data obtained from moisture susceptibility test.

Table 5: Experimental design layout and results for moisture susceptibility test

No of Runs	Factors		Responses		
	plastic Fiber (%)	Temperature (C)	ITS Dry (KPa)	ITS Saturated (KPa)	TSR (%)
1	0	24.98	105	93	88
2	0	24.99	95	83	87
3	0	25	93	75	80
4	0.3	24.98	118	105	89
5	0.3	24.99	111	95	85
6	0.3	25	107	93	87
7	0.5	24.98	134	121	90
8	0.5	24.99	127	115	90
9	0.5	25	121	105	87
10	0.7	24.98	95	75	79
11	0.7	24.99	93	73	78
12	0.7	25	90	72	80
13	1	24.98	76	56	74
14	1	24.99	69	54	78

15	1	25	68	45	66

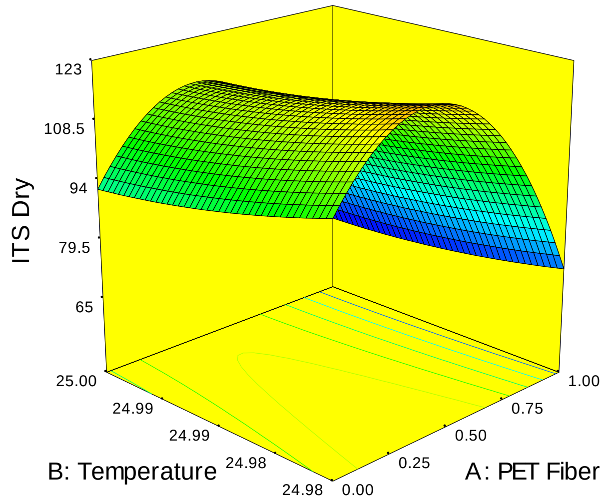

Fig. 2: Surface plot of dry indirect tensile strength versus Temperature and PET fiber percentage

Fig. 2 is a pictorial surface plot for dry sub-set's indirect tensile strength, the trend shows an increase in tensile strength for reinforced mixtures at 0.3% and 0.5% plastic fiber by 13% and 23% respectively compared to neat mixture but decreased at 0.7% by 4% and 1% by 27%. This may be caused by excess plastic fiber that tends to replace aggregates.

Fig. 3 is a surface plot for conditioned samples (saturated), the tensile strength improvement was 14% at 0.3% and 26% at 0.5% fiber reinforcement. The improvement in the tensile strength of reinforced mixtures is guided by high tensile strength of recycle plastic fiber at the test temperature (25^{o}C). The stiffness and storage modulus of plastic fiber tends to restrain the reinforced mixture from responding to the applied tensile stress. The tensile strength of saturated sub set was reduced by 12% at 0.7% fiber reinforcement and reduced by 34.5% at 1.0% fiber reinforcement.

Fig. 4 is a pictorial surface representation of tensile strength ratio for neat and reinforced bituminous mixtures. From this figure, the TSR of all mixtures excluding 1.0% reinforced mixture have satisfied AASHTO T283 requirement of ≥80% TSR value[14]. In addition, the TSR values for 0.3% and 0.5% reinforced mixtures are higher than that of control mixture. This is attributed by very low water absorption of plastic fiber (0.2%) and high storage modulus at 25^{o}C. This result is similar to the findings of research conducted on reinforced bituminous mixture with lignin, brucite, basalt and polyester by Xiong et al. [20].

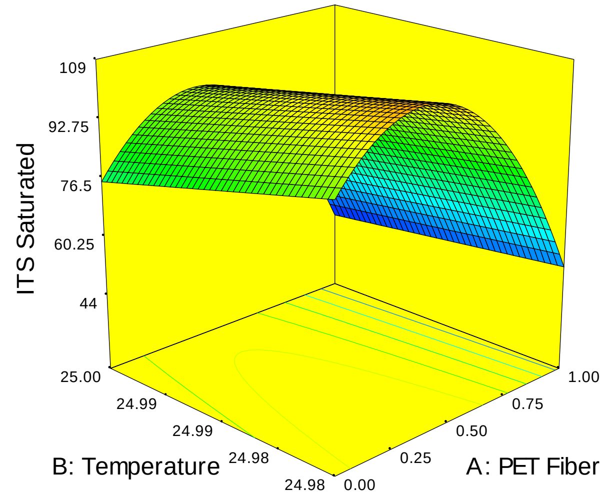

Fig. 3: Surface plot of saturated indirect tensile strength versus Temperature and plastic fiber percentage

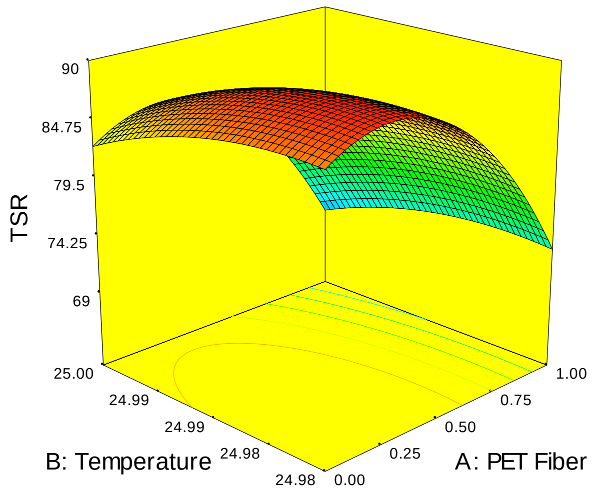

Fig. 4: Surface plot of tensile strength ratio versus Temperature and plastic fiber percentage

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$$ITS\ Dry = 113.71 - 14.83A - 4.9B + 1.38AB - 31.7A^2 + 1.7B^2 \quad (2)$$

$$ITS\ Saturated = 99.32 - 17.99A - 6B + 2.28AB - 33.02A^2 + 0B^2 \quad (3)$$

$$TSR = 87.05 - 6.7A - 2.0B + 0.26AB - 7.44A^2 - 1.6B^2 \quad (4)$$

Equations 2, 3 and 4 are the models generated by RSM for ITS dry, ITS saturated and TSR respectively. Analysis of variance was conducted to check the validity of these models and data statistically, the result is summarized in Table 6.

Table 6: ANOVA analysis for moisture susceptibility test result

Parameter	ITS Dry	ITS Sat	TSR	Remarks
Model p-value	0.0024	0.0039	0.0007	Significant
Model f-value	9.18	8.1	6.76	Significant
R^2	83.6	81.7	79	Significant
R^2 Adjusted	74.5	71.6	67	In agreement with predicted R^2
R^2 Predicted	66	63	59	In agreement with adjusted R^2
Adequate Precission	8.8	8.4	7.8	Adequate signal

From Table 6, the p-values for all the results are significant, and also the model f-values are significant. The coefficients R^2 are also significant at 95% confidence level, R^2 predicted and R^2 adjusted have all agreed to each other hence the analysis is acceptable. The precisions of the generated models are all adequate as are all above the minimum requirement of 4.

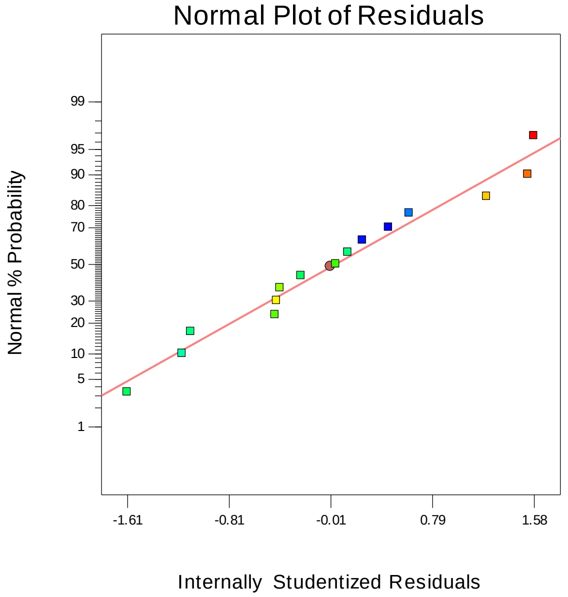

Fig. 5: Normality plot for indirect tensile strength of dry sub set data

Fig. 5, 6 and 7 are the normality plots for ITS dry, ITS saturated and TSR respectively. The plots show that all the data are located around the graphs' line which is a clear indication of the normality of data.

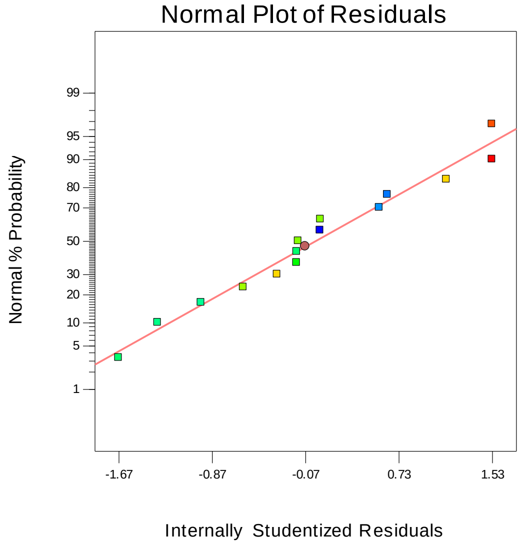

Fig. 6: Normality plot for indirect tensile strength of saturated sub set data

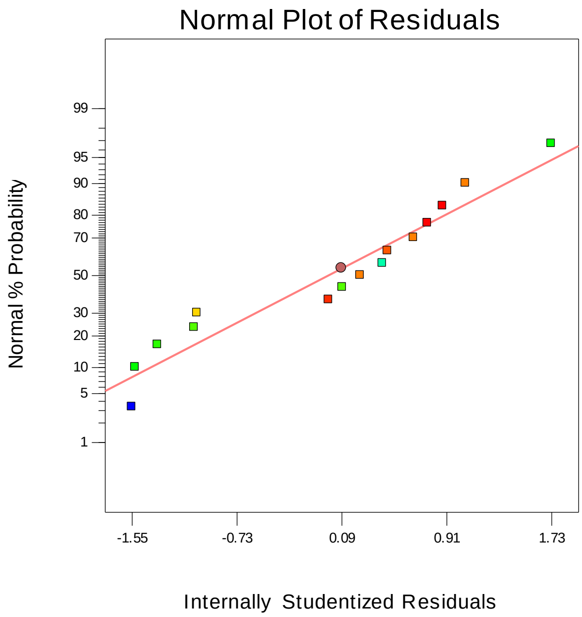

Fig. 7: Normality plot for tensile strength ratio (TSR) data

5. Conclusion

The stripping/moisture damage resistance of control and recycle plastic fiber reinforced mixtures was evaluated using moisture susceptibility test. The result indicated highest TSR value in mixtures containing 0.5% recycle plastic fiber followed by mixtures containing 0.3% compared to control mixture. Further addition of recycle plastic fiber at 0.7 and 1.0% yielded decrease in dry ITS, saturated ITS and TSR values. Therefore, it is concluded that 0.5% addition of recycle plastic fiber is the optimum dosage for moisture damage resistance in bituminous mixture.

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