MODIFICATION OF HOT MIX ASPHALT USING POLYETHYLENE THEREPHTHALATE (PET) WASTE BOTTLES

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ABSTRACT- This study covers usage of Polyethylene Therephthalate (PET) waste bottles to modify the properties of hot mix asphalt (HMA) mixtures. The study adopted usage of ground PET waste bottles with maximum particle size of 2.36 mm with different contents (0.1%, 0.3%, 0.5%, 0.7%, 0.9%, and 1.1% by the weight) to replace an equivalent portion of fine aggregate. The study involved a number of laboratory tests to investigate the effects of the mentioned PET content on the engineering properties of HMA. In addition to tests implemented to specify the properties of materials used and to determine mixing and compaction temperatures, the testing program included Marshall tests, rutting susceptibility tests, and indirect tensile strength tests applied on a number of control (unmodified) and modified samples. The results exhibited significant improvement in engineering properties of mixtures modified with optimum PET content (which was found to be 0.5%) in terms of increase in stability, stiffness, and indirect tensile strength and decrease in rutting susceptibility without adverse effects on the other desirable properties of the mixture.

المستخلص- تغطي هذه الدراسة استخدام مخلفات القناني البلاستكية لتحسين خواص الخلطات الأسفلتية الساخنة. تبنت الدراسة استخدام البلاستك المسحوق بمقاس حبيبي لا يتجاوز 2.36 ملم و بنسب اضافة مختلفة يشمل (0.1%؛ 0.3%؛ 0.5%؛0.7%؛ 0.9%؛ و 1.1% من وزن الركام) لاستبدال كمية مكافئة من الركام الناعم بالمضاف المقترح. شملت الدراسة عدد من الفحوص المختبرية لتبين تاثير المضاف المشار اليه و بالنسب المبينه اعلاه على الخواص الهندسية للخطات الاسفلتية الساخنة. بالاضافة الى الفحوص التي تم تبنيها لتحديد خواص المواد المستخدمة و لتحديد درجات حرارة المزج و الرص؛ شمل برنامج الفحوص فحص مارشال و فحص التخدد و فحص الشد غير المباشر. تم اجراء هذه الفحوص على عدد من النماذج غير المحسنة و تلك المحسنة بالنسب المشار اليها. بينت النتائج تحسنا مؤثرا في الخواص الهندسية للخلطات المحسنة بالنسبة المثلى (0.5%) من المضاف المقترح. يلاحظ زيادة الثبات و الصلابة و مقاومة الشد غير المباشر و انخفاض قابلية الخلطة للتخدد دون تاثير سلبي على خواص الخليط.

***Keywords**: PET, Marshall Properties, Rutting Susceptibility, ITS*

INTRODUCTION

Highway networks cover hundreds millions of lane-kilometers and supporting millions of vehicle-kilometers each year in the world [1]. Highways represent the main infrastructures in transportation [2] which controls the growth of economy [3-5] especially in developing countries [6]. Asphaltic pavements can be considered as one of the most important elements in highways engineering [7]. Generally, most of the highways are paved with HMA pavements [8]. Therefore, modification of HMA pavements is an essential objective [9] as it increases its performance and service life and decreases its maintenance cost. Several traditional additives are used in modification of HMA [10-21]. However, using these traditional additives adds supplementary cost. Recently, there is a revolution in employment of waste materials in modification of HMA [22-31]. PET waste material is widely used to improve the properties of construction materials [32-46]. Therefore, using this waste material (PET) in modification of HMA can promotes sustainable construction especially when refer to the fact that HMA is one of the most used construction materials due to the huge volumes of highways projects. A number of researches were performed in this domain [47-62]. Ahmadinia et al. (2011, 2012) and Baghaee et al. (2012) studied the performance of PET on stone mastic asphalt [47-49]. The project includes a series of researches, majorly, focused on resistance of mastic asphalt to permanent deformations. Vasudevan et al. (2012) proposed a technique to use PET in flexible pavements [62]; similar approach was adopted by Gürü et al. (2014) [56]. Rahman and Wahab (2013) studied the possibility of using recycled PET in HMA based on Malaysian standards and conditions [60]. Baghaee et al. (2014, 2015) studied the effects of PET on permanent deformations in asphalt mixtures under dynamic and static loads [50-54]. In addition to laboratory approach, the researches adopted theoretical approaches including statistical analysis and neuro-fuzzy methodology to achieve the objectives of the researches. Modarres and Hamedi (2014) and Dehghan and Modarres (2017) adopted PET fibers to study the fatigue characteristics of HMA [55, 57,58]. Soltani et al. (2015) adopted response surface methodology to analyze fatigue properties of HMA mixed with PET. Moghaddam et al. (2016) adopted a theoretical approach involving genetic algorithm, neural network and fuzzy logic to estimate the fatigue life of MHA modified with PET waste [59]. However, the research in this domain must be extended to cover more effects of PET on the properties of asphalt mixtures. Therefore, this study aims to fill the gaps left in the other researches through adopting additional tests, different asphalt grade, different PET contents and particles' size, and different aggregate origin and gradation. In addition, the present study aims to study the long term effects of using PET as a HMA modifier under different conditions such as saturation and freezing and thawing cycles. This study selected PET waste bottles due to its great availability everywhere. This paper covers a laboratory-oriented study to investigate the effects of using different PET contents (0.1%, 0.3%, 0.5%, 0.7%, 0.9%, and 1.1% by the weight of aggregate) on the engineering properties of HMA. The PET content was considered to replace equivalent amount of fine aggregates as the particle size of PET used in this study is within the range of fine aggregate. This action (equivalent replacement) ensures constant asphalt contents in prepared samples. The testing procedure includes a number of tests to specify the properties of materials used and viscosity tests to determine mixing and compaction temperatures related to predetermined asphalt viscosities. In addition, the testing program applied on unmodified and modified samples includes Marshall tests, rutting susceptibility tests, and indirect tensile strength tests (ITS) for unconditioned and conditioned samples. The results exhibited significant improvement in engineering properties of modified samples compared to those of control (unmodified) samples.

MATERIALS AND METHODS

a. Aggregate

The aggregate used in this investigation was obtained from Al-Nibaee in Salah Aldine Governorate. Generally, the aggregate used in this study is angular, and free from clay, organics, and foreign materials. It has uniform quality, composed of sound, tough, and durable particles. To investigate the properties of aggregate, a number of tests were performed. All properties comply with the requirements of Iraqi standard specifications for roads and bridges where applicable as shown in Table 1. The gradation of the aggregate is illustrated in Figure 1.

b. Asphalt cement

The asphalt cement used in this investigation was obtained from Al-Dora refinery in Baghdad city in Iraq. The properties of asphalt cement used in this study were investigated based on extensive laboratory testing. The results of the tests were compared with Iraqi requirements where specified. All properties comply the requirements of Iraqi standard specifications for roads and bridges as shown in Table 2.

c. PET

PET is a semi-crystalline polymer has high tensile strength, high chemical resistance, and melting point of 260±10^{o}C [63]. PET waste bottles, in this study, were collected from local trash and, mechanically, grinded into fine particles (not more than 2.36 mm) to replace an equivalent portion of fine aggregate of HMA mixtures. The main properties of PET used in this study are presented in Table 3.

This work, carried out in Khartoum North Power Station. The power station included two generators: unit 1 and unit 2. The implementation of the work involves two main steps: formulation of economic dispatch problem and developing of genetic algorithm solution.

TESTING PROGRAM

In addition to the tests performed to study the properties of materials used, a number of tests were implemented to determine the mixing and compaction temperatures and the optimum asphalt content and to investigate the effects of PET on the properties of HMA as described in the following subsections.

a. Viscosity Tests

The viscosity of asphalt was determined with different temperatures (120°C, 135°C, 150°C, and 165°C) in accordance with ASTM D 2170 to specify suitable mixing and compaction temperatures. These temperatures were adopted to prepare Marshall specimens.

b. Marshall Test

This part of testing program involved preparation of a number of control asphalt mixture samples (each involved three specimens) at the determined mixing and compaction temperatures using Marshall method. The prepared samples were tested using Marshall method to specify the optimum asphalt content and to investigate the properties of control mixture. The investigation covered bulk specific gravity, stability, flow, air voids, total voids in mineral aggregate, and stiffness. Based on optimum asphalt content, Marshall method was repeated for samples modified with the predetermined contents of PET to investigate their effects on the properties of HMA.

c. Rutting Susceptibility Test

To evaluate the rutting susceptibility of the mixtures under this study, unmodified samples and samples modified by PET with different contents were prepared and tested according to AASHTO T 324; each sample involved two specimens with dimensions of (600mm x 200mm x 75mm). The prepared samples were tested using wheel tracking apparatus under full immersion conditions with temperature of 50°C. The applied pressure was about 730 kPa which simulates the contact tire pressure. The rut depth was recorded up to 20000 wheel passes.

d. Indirect Tensile Strength Test

Based on the predetermined optimum asphalt content (5.5% by weight of total mix) and the predetermined temperatures, a number of specimens were prepared for indirect tensile strength testing. The prepared specimens were of 100mm in diameter and 63.5±2.5mm in thickness. The prepared specimens had 7±0.5% air voids as required by AASHTO T283. To achieve the targeted air voids, a number of trials were implemented using Marshall compaction hammer to specify the suitable number of blows. Afterward, seven sets each involved two samples (one for unconditioned testing and the other for conditioned testing) were prepared to represent control mixture and mixtures modified with different PET contents. Conditioned specimens were subjected to vacuum saturation in accordance with AASHTO T283. In addition, the conditioned samples were subjected to freezing at -18±3°C; afterward, they were immersed in a water bath with temperature of 60±1°C for 24 hours. Unconditioned and conditioned specimens were tested at 25°C to determine the ITS values. The tensile strength ratio values were calculated by dividing the conditioned ITS values by unconditioned ITS values.

RESULTS AND DISCUSSION

a. Results of Viscosity Tests

From viscosity test for asphalt cement, the temperature ranges of mixing and compaction were determined to be (158-166: average=162) °C and (140-147: average=143.5) °C respectively; these temperatures are related to predetermined viscosities required for mixing (150-190 centistokes) and compaction (250-310 centistokes). These temperatures were adopted for preparation of Marshall Specimens.

b. Marshall Test Results

Table 4 presents the properties of the control mixture according to Marshall testing method. Based on these results the optimum asphalt content was determined to be 5.5% by weight of the mix. This percent was adopted to produce the modified mixtures. The results of Marshall tests exhibited that all properties of control and selected modified mixture conform the requirements of the standards. Figure 2 illustrates the effects of different PET contents on the properties of the mixture.

The results exhibited that the bulk specific gravity(Gmb) values of modified samples decrease with increase of PET content as shown in Figure 2-a. This behavior can be attributed to the decrease in overall specific gravity of aggregate (Figure 2-b) as a result to decrease in overall specific gravity of fine aggregate (Figure 2-c) with increase of PET content as the specific gravity of PET is less than that of fine aggregates; a portion of fine aggregate was replaced with equivalent amount of PET as, previously, mentioned. In addition, decrease in Gmb values with increase of PET content can be a result of decrease in mixture compatibility. Decrease in mixture compatibility can be justified by two reasons: inconsistence structure of PET and reduction in lubrication by hot asphalt during compaction due to absorption of an amount of asphalt by PET. Figure 2-d show that Stability values increase with increase of PET content up to 0.5% then decease with increase of PET content. Moderate content of PET produces stiffer mixtures which make them more stable compared to unmodified ones [48]. However, excessive PET content, possibly, absorbs high amount of asphalt, increases the heterogeneity of mixture, and reduces compatibility leading to decrease in stability. Figure 2-e exhibited that Marshall flow values decrease with increase of PET contents up to 0.3% then increase with increase in PET content. As mentioned, adding PET produces stiffer mixtures which decrease the flow. However, as excessive PET content decreases the stability, it increases the flow consequently. The values of Marshall stiffness follow a trend similar to that obtained for Marshall stability as shown in Figure 2-f. However, the highest stiffness value was attained using 0.3% PET content. These results are expected as stiffness value is the stability divided by the flow. Figure 2-g exhibited that the air void values increase with increase in PET content. Three possible reasons may justify this trend: PET absorbs an amount of asphalt, decrease the mixture homogeneity, and decrease compatibility; these factors increases the air voids. Figure 2-h shows that VMA values changed by increase in PET contents with a trend similar to that for air voids (Figure 2-g). However, the differences among VMA values related to addition of different PET contents are slighter than those of air void ones. The justification of this trend is similar to that stated in case of air voids trend.

c. Results of Rutting Tests

Figure 4-a illustrates the results of this test for unmodified samples and those modified with different PET contents. The results exhibited that the rutting susceptibility of modified samples is less than that of control samples. Figure 4-b abstracts the values of rut depth after 20000 wheel passes for unmodified and modified samples. However, rut depth values decrease with increase of PET content up to 0.5% then increases with increase of PET content. This behavior can be attributed to the generation of stiffer mixture using moderate PET content [47]. However, using excessive PET contents decreases the stability and increases the air voids which increase the rutting susceptibility. Unfortunately, mixtures with low rutting susceptibility are, normally, exhibit low resistance to cracking [64] which make them suitable for hot regions but not suitable for cold regions where cracking is more probable [65]. Although that, the modified mixtures (especially those modified with optimum PET content) have properties suitable even for cold regions as the flow values are within the acceptable range. In addition, the modified mixtures can be applied in cold regions with some adjustments including increasing the asphalt content and using softer asphalt cement initially. Precautions must be adopted when applying these adjustments to cover all engineering properties required in the mixture. Fortunately, the rut depth values in all samples are less than 20% of the samples' thickness which is acceptable in pavement technology [66].

d. Results of ITS Tests

The results of this tests of unconditioned samples (control and modified) exhibited that the ITS values of modified samples are higher than those of control samples as shown in Figure 5-a. This behavior is, probably, related to the reinforcing role of PET in the mixtures. ITS values obtained from testing of conditioned samples were similar to those obtained from unconditioned samples as modified samples exhibited higher ITS values than that attained by control samples as shown in Figure 5-a. These results differ from results stated by one literature [47]. This difference may be attributed to the differences in the properties of materials used. Figure 5-b presents the values of TSR; all were more than 80% which satisfies the requirements [66].

CONCLUSIONS

This study is a laboratory-oriented approach to investigate the effects of different contents of PET on the engineering properties of HMA. From the results of the tests stated in the previous subsections, addition of PET to the HAM improves its engineering properties. PET content of 0.5% can be considered as the optimum content as it produces highest stability, lowest rutting susceptibility and fulfills the requirements of the other parameters. However, 0.3% can be considered as alternative optimum content (local optimum) as it produces higher stiffness, lower air voids (nearest to the most desirable value which is 4%), and lower flow compared to those attained using 0.5% of PET. This content (0.3%) can be adopted in hot regions to prevent pavement distortions (due to low flow and high stiffness) and asphalt bleeding (due to sufficient air voids) without adverse effects on durability (as air voids value is less than 5%). Therefore, this study recommends using PET as waste material as an effective additive in HMA technology.

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Table 1: The properties of aggregate

	Unit	Test	Specifications	Test Result	Compliance
Los Angeles Abrasion Value	%	AASHTO T 96	<30	14	Comply
Plasticity Index	-	AASHTO T 89	<3	0	Comply
Gypsum Content	%	BS 1377	<1	0	Comply
Flakiness	%	BS 812	<20	3	Comply
Soundness	%	AASHTO T 104	<12*	2.1	Comply
Gsb_{ca}**	-	AASHTO T 84	-	2.650	NA
Gsb_{fa}**	-		-	2.748	NA
Gsb_{mf}**	-		-	2.700	NA
Gsb_{agg}**	-		-	2.716	NA

*American specifications were applied where Iraqi specifications are unspecified
** Gsb_{ca}, Gsb_{fa} , Gsb_{mf}, Gsb_{agg} =Bulk Specific Gravity of coarse aggregate, fine aggregate, mineral filler, and overall aggregate respectively

Table 2: The properties of asphalt

Property	Conditions	Test	Specifications	Asphalt Used
Penetration, 0.1 mm	25 °C , 100g, 5 Sec	AASHTO T-49	40-50	47
Flash Point, °C	Open Cup	AASHTO T-78	>240	267
Loss on Heating, %	5hrs., 163 °C	AASHTO T-47	<0.75	0.50
Penetration After Heating, %	Based on Original	AASHTO T-49	>52	61
Ductility, cm	25 °C, 50 mm/min	AASHTO T-51	>100	>100
Softening Point, °C	Ring and Ball	AASHTO T-53	54-60	54
Increase of Softening Point, °C	Ring and Ball 5hrs., 163 °C	AASHTO T-53	<10	8
Solubility, %	Organic Solvent	AASHTO T-44	>99	99.99
Specific Gravity	Pycnometer, 25 °C	ASTM D-70	NA	1.02

Table 3: Properties of PET

Particle Finer than	2.36 mm	AASHTO T 127	100%
	1.18 mm		50%
	0.425 mm		0%
Specific Gravity		ASTM D 792	1.385
Melting Point		-	255°C

Table 4: Properties of control mixture based on Marshall method

Asphalt content (% by total weight of mix)	Specific Gravity (Gmb)	Marshall Stability (kN)	Flow (0.25 mm)	VMA (%)	Air Voids (AV) (%)	Stiffness (kN/mm)
4.5	2.407	12	6.2	15.4	5.2	15.52
5	2.441	14.49	8.1	14.6	4.6	14.32
5.5	2.470	15.61	11.5	14.1	4.2	10.88
6	2.462	11.88	13	14.8	3.5	7.28
6.5	2.451	8.81	15.1	15.6	3	4.64
7	2.443	7.73	18.9	16.3	2.7	3.28
7.5	2.420	6.04	21.2	17.6	2.1	2.24
Values related to optimum asphalt content						
5.5	2.464	14.7	11.7	14.1	4.1	10.05

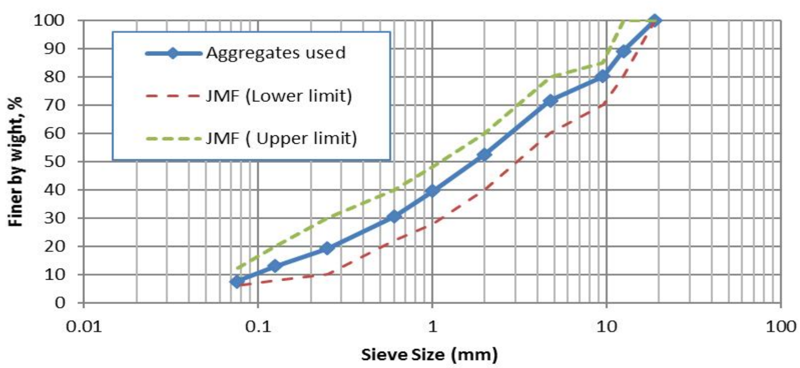


Figure 1: Aggregate gradation

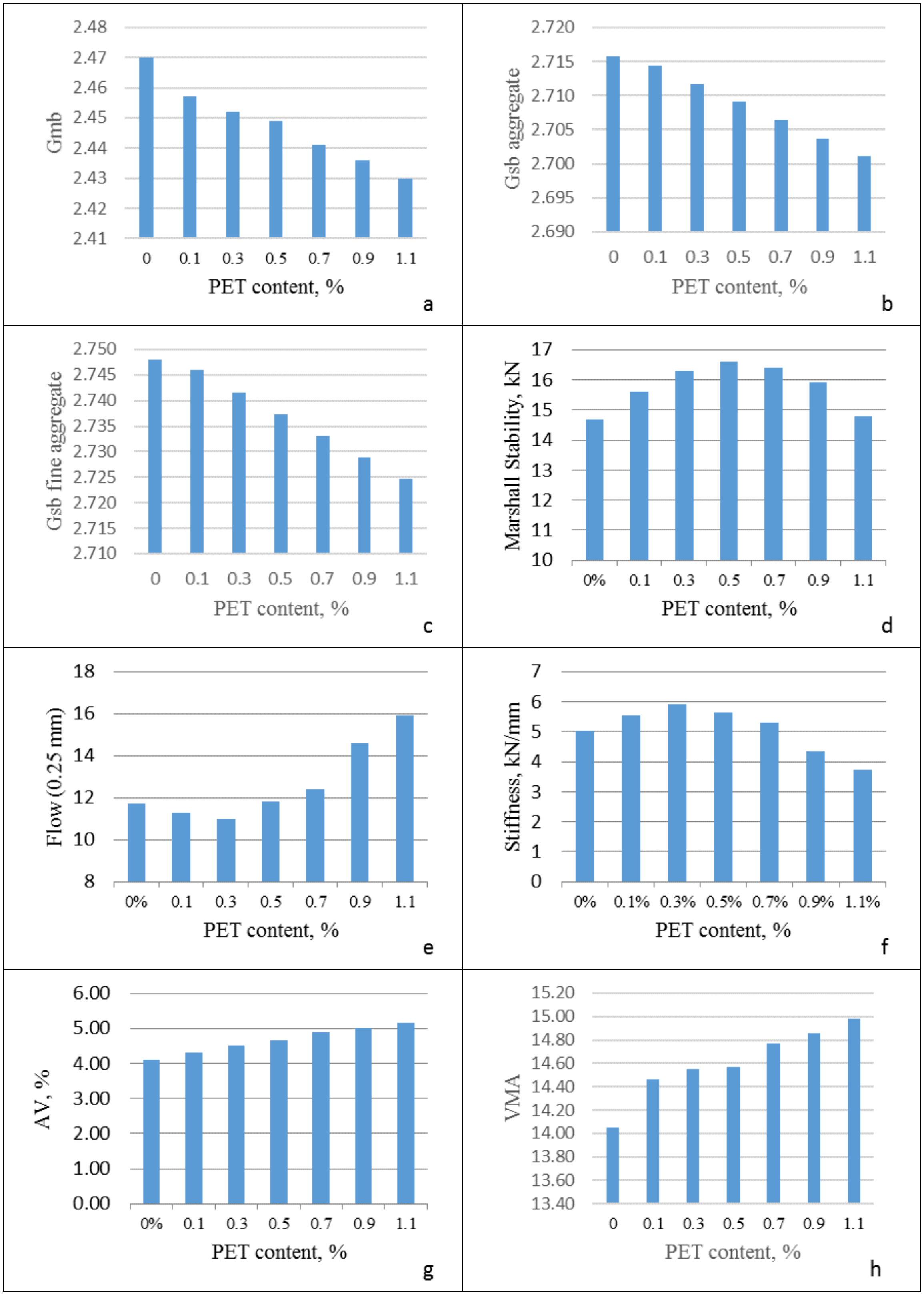
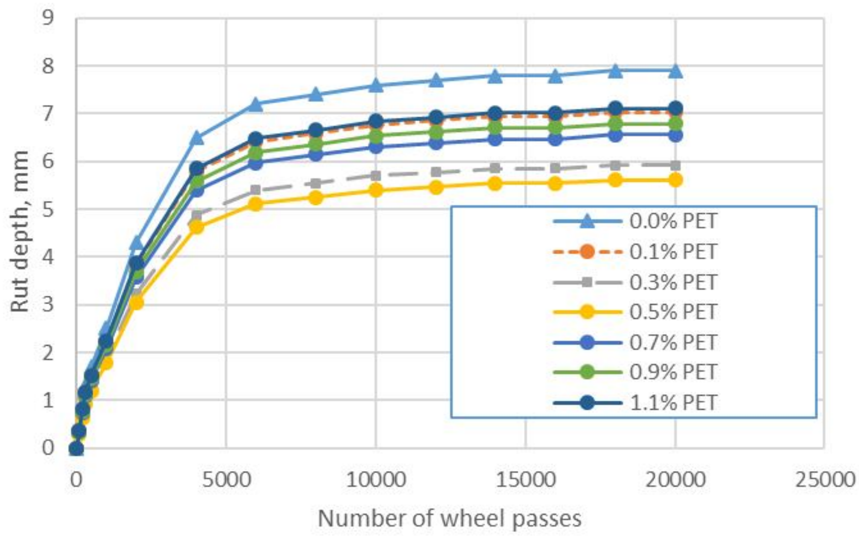
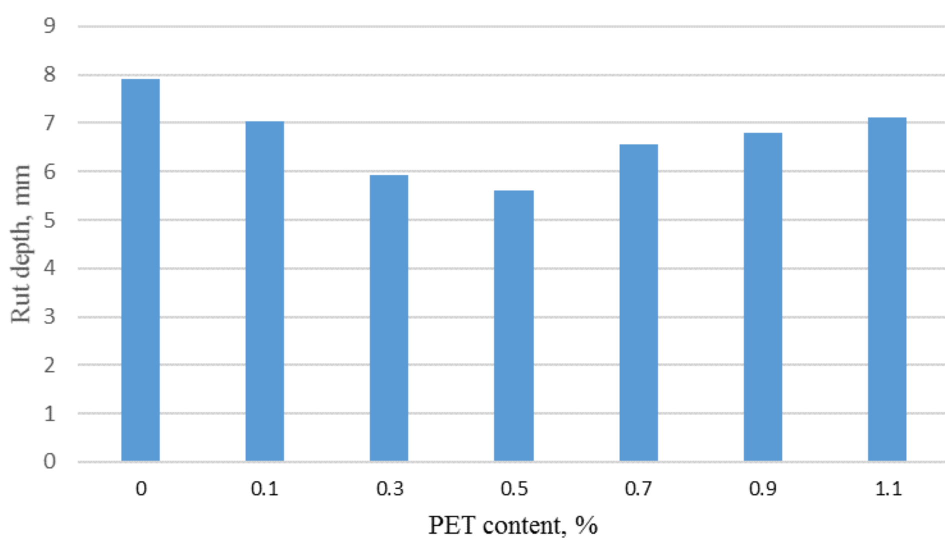


Figure 2: Results of Marshall tests



a



b

Figure 4 Results of wheel track rut depth

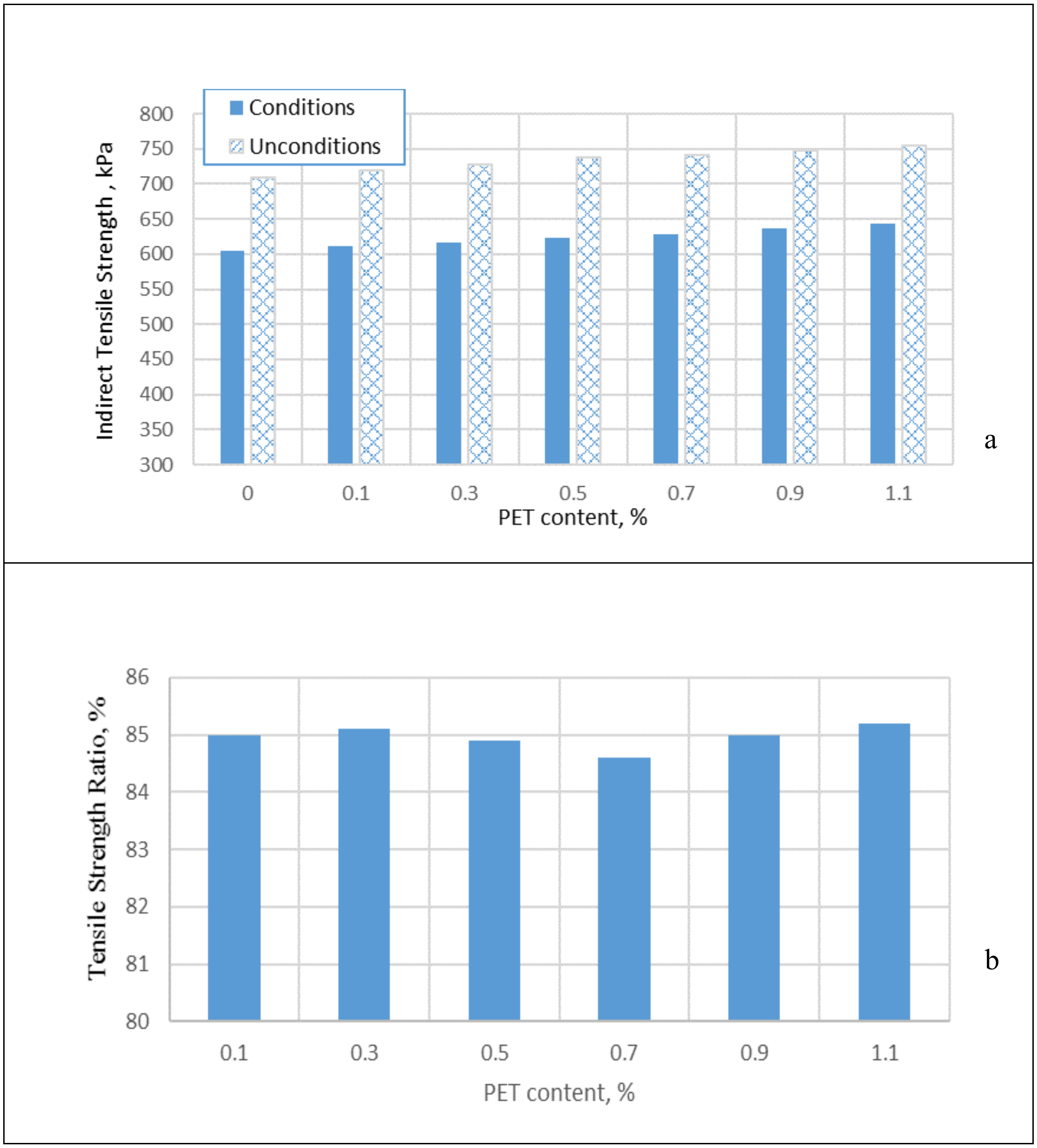


Figure 5 Indirect Tensile Strength tests results of unconditioned and conditioned samples