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UTILIZATION OF WASTE PLASTICS TO ENHANCE THE PERFORMANCE OF MODIFIED HOT MIX ASPHALT

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ABSTRACT: Large quantities of refused plastic material were produced due to industrial development. These solid waste having an adverse impact on environment. Moreover, the increase of the plastic refuse which causes severe fear for public led in parallel to search effective and useful manner to find out any other method to sustainable. The paper was conducted to find out any treatment for the problem of the management of plastic municipal solid waste (MSW) in Jordan using as additive in the modification of road aggregate performance. In the same time, this will contribute to reduce the environmental impact of the plastic solid waste. This refused plastic was utilized to improve the asphalt performance. The first sets of experiment were carried out upon a six samples were tested with asphalt percentages of (5, 5.5, 6, 6.5, 7 and 7.5) at 60ºC and the results gave that the optimum asphalt ratio was to be 7%. The second sets of testing were conducted for the optimum amount of refused plastic added to another six sets of samples tested at different percentage of refused plastic as follows (2, 2.5, 3, 3.5, 4 and 4.5 %) at 60ºC and the results gave that the optimum ratio of plastic added was 4%. The results of the comparative study between hot mix asphalt and modified hot mix asphalt show that the addition of plastic has a significant positive effect on the properties of HMA, and mitigating the adverse effect on the environment.

Keywords: Asphalt, Refused Plastic, Modified Asphalt, Durability, Chemical Stabilization.

1. INTRODUCTION

Asphalt consists of the resins, aromatic hydrocarbons, and saturates (paraffin and naphthenic) [8] and [18]. Plastic's reactions with asphalt components changes the rheological properties of asphalt binder and the required optimum asphalt content for the mixture design, which plays a key role in the formation of the interface bonding between plastic and asphalt. Many researchers confirmed that additives of different materials to the asphalt content in aggregate specimens may strengthen and modified the aggregate properties. Different additives were used for this purposes, for example, over 60 years ago in South Carolina, coarsely-woven cotton layers were spread between coats of asphalt to strengthen the road surface and comfort the ride [4], [10], [17] and [3]. Effective waste material re-use is one of the many ways to solve the problem of excessive solid waste material in industrial and urban areas. Reusing waste materials can make a significant contribution to the environment and economy from different aspects, namely: (1) it helps reduce the overuse of natural resources and saves them from exhaustion, (2) it helps reduce the environmental pollution level as a result of the waste materials generated in urban and industrial areas, and (3) it contributes to saving energy and money [12]. Waste re-use is especially vital in dealing with certain discarded materials such as plastic containers, which, due to their longer biodegradation period, are extremely harmful to the environment and ecosystem balance. Therefore, in order to reduce their negative impact on the environment and nature, it is logical to re-use these waste materials in engineering and industrial construction and production [3] and [6]. Cotton served both as a binder for the asphalt cement and waterproof blanket to restrain water from seeping through cracks and eroding the road base. Chandra and others in their research adapted a four compaction temperatures were 97, 116, 135, and 154°C. This range was selected based on the temperatures 135 and 154°C, which are commonly used as short-term oven-aging temperatures in the laboratory to simulate binder aging and absorption during the construction of HMA pavements which confirmed by Asphalt Institute 2003. The compaction temperatures of 97 and 116°C were selected to evaluate the effect of warm mix additives at relatively lower temperature [2]. Additives react with asphalt in aggregate producing new compounds that are changed in their chemical and mechanical properties. Plastic waste has started to attract increased public attention, notably due to a growing number of different amounts of plastics waste generated. Plastic industry, in Jordan and other countries, generates thousands of tons of plastics waste which goes into landfills every year. These plastics wastes can provide high strength, good abrasion resistance, and can withstand deterioration from some chemical, mildew, and rotting [5]. Plastics solid wastes make excellent candidates for various civil engineering applications including pavement rehabilitation and road construction. As a result, different waste materials were explored and recycling for environmental and economic advantages and also the possibility of solid waste reuse in road construction [17].

Polyethylene Terephthalate (PET) and High density Polyethylene (HDPE) are used in most bottling applications of water, yoghurt and soft drinks, but in terms of littering, however, one of the worst culprits is polyethylene (or “polythene”) bags, for food packaging and sachet water bags. Every day, a multitude of items that are either partly or completely made of plastic are used and these plastics eventually end up in the landfills. Depending on the quality of the plastic, it may take anywhere from a few days to several years to break down in landfills, but it never breaks down completely into particles that can be used in nature. As such, plastic is one of the worst offenders when it comes to environmental pollution [19].

1.1 Research Objectives

The main objective of this study is to investigate the potential use of plastic refuse as a modifier to improve the performance of hot mixed asphalt (HMA) under the influence of water effects which can be affect the surface course of flexible pavement during and placed in service. Other secondary objectives include, determination and comparison of the mechanical properties of hot mix asphalt samples with and without additive of plastic refuse.

1.2 Research Scope

This study investigated the volumetric properties of hot mixed asphalt – (HMA) mixtures containing different percentage of refuse plastics additives tested at small scale of time intervals from 0 up to 16 hours at fixed testing temperature of 60oC (Marshall’s test procedures). Four sets of mixtures, including pure asphalt and different percentages of refuse plastics - modified were prepared and tested for volumetric properties. The mixtures were subjected to subsequence changes of time from 0 to 16 hours with optimum values of asphalt and refuse plastics additives.

2. METHODOLOGY AND TESTING PROCEDURES

2.1. **Materials and Aggregate Preparations**

The aggregate was obtained from locally source cleaning with tap water at ambient temperature (23ºC), then the aggregate was washed with tap water again. After that the aggregate dried at 105ºC for 24 hours to elaborate the water content. Sieving analysis was done to separate the appropriate size of aggregate according to Jordanian Standards. Marshall Specimens were prepared in the laboratory conditions according to Marshall’s Test Procedures ASTM D1559-76.

2.2. Physical and Mechanical Testing and Specifications

Testing of some mechanical and physical properties of the aggregate were executed. This includes gradation, Los Angles abrasion test, absorption test and optimum ratios of aggregate amounts as shown in Tables 1, 2 and 3. Table 1 shows the gradation tests according ASTM D 422 - Standard Test Method for Particle-Size Analysis of soils. Resulted physical properties of the asphalt specimens were tabulated in Table 4 - column 2, which shows the standard method used with corresponding values and units in columns 3 and 4, respectively.

Table 1 Specification Job Mixture (Sieve analysis)

Sieve #	Passing (%)	Retained (%)	Retained between (%)
1”	100	0	0
¾”	95	5	5
½”	85	15	10
3/8”	67	33	18
#4	42	58	25
#8	27	73	15
#40	14	86	13
#50	9	91	5
#100	6	94	3
#200	5.7	94.3	0.3

Table 2 The Los Angeles (L.A.) Abrasion Test Results

Properties	Test method	Value
L.A. abrasion (%)	ASTM C-131	31.2%

Table 3 Specific Gravity of Aggregate

Type of Materials	Specific gravity
Coarse aggregate	2.50
Fine aggregate	2.62
Filler	2.71
Asphalt	1.05

2.3. Identifying of Optimum Bitumen Content of Hot Mixed Asphalt (HMA) Samples

The identifying of Optimum Bitumen Content (OBC) for (HMA) samples using Marshal Mix design procedure have been examined for a six sets of samples (3 samples for each set) with different percentages of asphalt including 5, 5.5, 6, 6.5,7 and 7.5% by weight. This was done to determine the best percentage (optimum ratio) of bitumen content for the aggregates used. Marshal stability, flow, specific gravity and air voids were determined at 60^{o}C.

2.4. Identifying Of Optimum Bitumen Content of Hot Mixed Asphalt (HMA) With Refuse Plastic Samples

Again the same procedures were adapted to identify the Optimum plastic refused Content for (HMA) samples mixed with plastic refuse additives using Marshal Mix design procedure. A total of 15 samples were prepared for 2% to 6 % plastic refuse with 1% incremental by weight of (OBC), at 60^{o}C.

2.5. Immersion Time Effect Studies

The time effects on samples properties were achieved by preparing preliminary samples from HMA without plastic refuse includes 15 samples at the time intervals of 1, 2, 4, 8 and 16 hours, 3 sample each set at 7% of asphalt OBC percentage. These experiments were done to determine the effect of time on these mixture mechanical properties at 60^{o}C. The second part of this research was executed to determine the effect of time on asphalt OBC with refuse plastic mixture at 60^{o}C, which include preparing 15 samples of HMA with 4% of plastic refuse percentage additives.

2.6. Limitations

The results obtained depend on set of limitations and criteria that were taken into account during the experimental work. These limitations are as follows, percentages of asphalts cement are utilized in HMA within the range of 5 – 7.5% with 0.5% by weight increments, percentages of plastic refuse are utilized in asphalt mix within the range of 2 – 6% with 1% by OBC asphalt weight increments, only one type of plastics refuse was studied as a modifier of asphalt mixtures and finally the long effect (more than 16 hours) of water immersion on the performance of the HMA is not investigated in this report due to the time constraint, finally the composition of plastic refuse wasn't analyzed since it is a solid waste and generally it has the composition of polyethylene plastic bags and can be describe as shown in Table 5 below.

Table 4 Bitumen Utilize in Experiments for Physical Properties

Test (1)	Method (2)	Unit (3)	Value (4)
Penetration at 25 0C, 100 g, 5 s	ASTM D 5-97	1/10 mm	60 -70
Flash point	ASTM D-92	^{o}C	312
Fire point	ASTM D-92	^{o}C	331
Ductility (25 ^{0}C)	ASTM D-92	cm	103
Softening point	ASTM D-36	^{o}C	52

Table 5 Polyethylene Plastic

Properties:	Value:
Tensile Strength:	0.20 - 0.40 N/mm^{2}
Thermal Coefficient of Expansion:	100 - 220 x 10^{-6}
Max. Continued Use Temperature:	65 ^{o}C (149 ^{o}F)
Melting Point:	110 ^{o}C (230 ^{o}F)
Density:	0.910 - 0.940 g/cm3

3. RESULTS AND DISCUSSION

3.1. Marshal's Test Results

Laboratory work results are carried out in two stages, firstly stage represents the Marshal's Test which is carried out with different percentages of bitumen at (5, 5.5, 6.5.7 and 7.5%) (w/w) %. The results are analyzed in order to obtain the optimum bitumen content (OBC), secondly stage was related to study the behavior of mechanical properties of the samples with addition of different percentage of plastics waste refused to asphalt content. Determination of the optimum bitumen contents (AC) are represented in Fig.1. Corresponding physical properties results of hot asphalt specimens are shown in Figs.1, 2, 3, 4, 5 and 6, for bulk specific gravity, stability, air voids (V_a), voids in minerals aggregate, flow and voids percentage filled with asphalt, respectively. It was found that the optimum bitumen content (OBC) was 7% of asphalt to aggregate (weight by weight ratio). Fig.1 shows that as the bitumen content increase the bulk specific gravity until it reaches 7 % content of asphalt, after that specific gravity is decreased. As the percentage of asphalt increases in samples the sliding of aggregate is increased which produce to the inter-locking of aggregate with each other. After a 7% of (OBC) the effect of asphalt is inversely as shown in Fig.1. The property of bulk specific gravity is very important for pavement design.

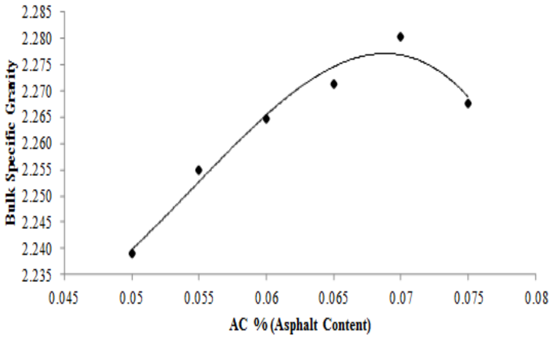

Fig.1 Bulk specific gravity of asphalt mix – asphalt Content relationship

Fig. 2 shows the behavior of stability (kg) with asphalt content (AC) percentage variations. The results give that as the asphalt content increases the stability increase up to critical value furthermore it decreases. It was found that the highest stability value is 1230 kg at the optimum asphalt content of 7 percent. On the other side Fig.3 shows the relationship between the air void (V_a) versus the asphalt content AC. It is clear that as the asphalt content increase the air voids are decrease.

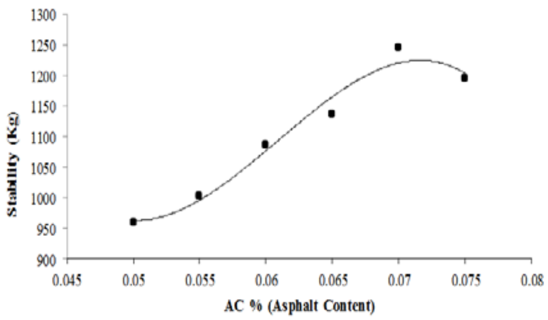

Fig.2 Stability–asphalt content relationship

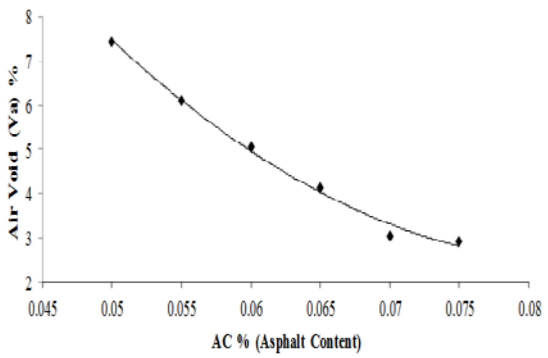

Fig.3 Air voids–asphalt content relationship

The relationship between asphalt content and voids in mineral aggregates is represented in Fig.4. It is clear that as the asphalt content increased the voids in mineral aggregates. This may refer to less attraction between the aggregate particles in the samples generated in case of higher asphalt content in the specimens. This in agreement with the results achieved as in [13].

A good point to discuss is that at high percent of asphalt content (i. e., above 7 %) where the stability of the specimens decrease. This may be attributed to the increase in permeability of asphalt inside the aggregates that dents the aggregate to absorb high amount of asphalt and this behavior compile with the results achieved as in [7], which states that " at percent air voids above 8 percent, small changes in air voids leads to a large increases in permeability".

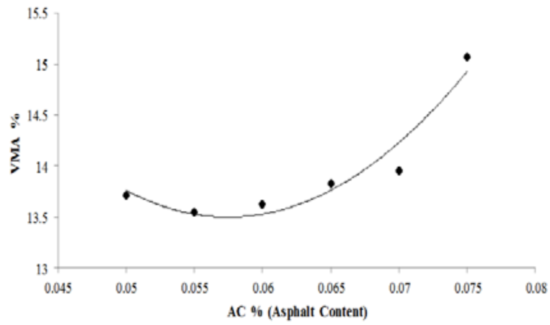

Fig.4 Voids in mineral aggregates –asphalt content relationship

Fig.5 shows flow results for different bitumen contents. Flow of asphalt mix increases as the bitumen content increased.

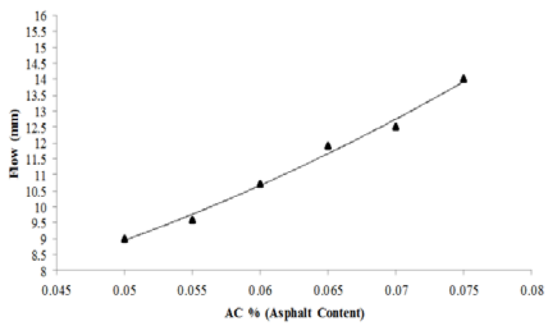

Fig.5 Flow–asphalt content relationship

Fig.6 shows the voids percentage filled with asphalt (VFA %) results for different bitumen contents. Minimum VFA content value is at the lowest bitumen percentage (5%), VFA% increases gradually as bitumen content increases due to the increase of voids percentage filled with bitumen in the asphalt mix.

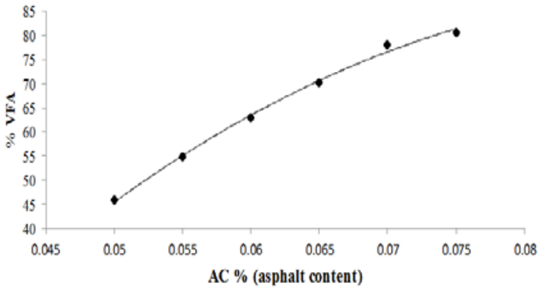

Fig.6 Voids percentage filled with asphalt - asphalt content relationship

Improvement in the properties of hot mixed bitumen are summarized as follows the asphalt content at the highest stability is 7.2 %, the asphalt content of 6.5% was achieved at the allowed percentages of air voids (V_a) of 4 %, the asphalt content at the highest value of bulk density bulk density = 7%, the optimum asphalt content (OBC) = (7.2+6.5+7)/3 = 6.9% or (OBC) = 7%.

3.2. Part two - hot mix asphalt with plastic refuse.

3.2.1. Stability

This part of research corresponds to the results of testing the hot asphalt specimens mixed with plastic refuse (PR) . As shown in Fig.7 the stability of an asphalt sample is increased up to a value after which it is decreased. This value of stability was found to be 1460 KG at optimum bitumen content (OBC) of 7% mixed with 5% of refused plastic (w/w) ratio (plastic / asphalt content). A comparison between the results in part one Fig.1 where the stability was found to be 1225 KG at optimum asphalt content (BOC) of 7% with the new value of 1460 KG as shown in Fig.7 below, this means that an addition of 4.7 % of refused plastic increases the stability of asphalt sample with a value of 235 kg with 19.1 % stability percentage increased at critical conditions.

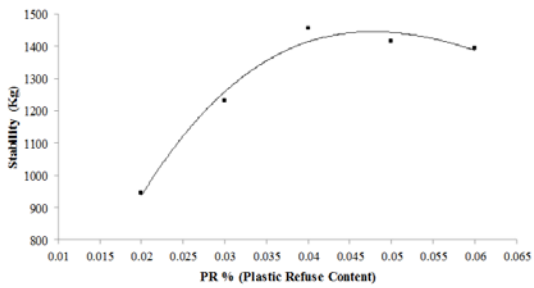

Fig.7 Stability values with varying plastic refuse content

3.2.2. Bulk specific gravity

Since, the bulk specific gravity (of solids) is defined as the ratio of the mass in air of a unit volume of a permeable material (including both permeable and impermeable voids normal to the material) at a stated temperature to the weight in air of equal density of an equal volume of gas-free distilled water at a stated temperature. As shown in Fig.8 any increase in plastic content increase the bulk specific gravity of the mix up to maximum value of 2.29 at 4.3 % content. After that the value is decreasing. The resulting decrease in the bulk specific gravity value may be due to the lower specific gravity of the plastic material in comparison with the mineral aggregates.

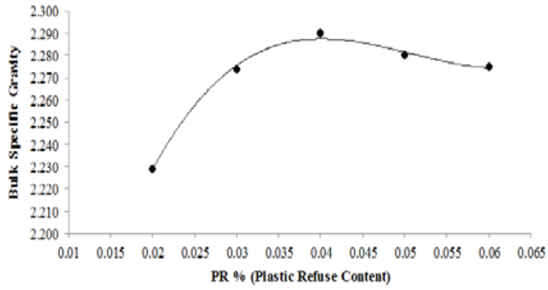

Fig.8 Bulk specific gravity of asphalt mix – plastic refuse Content relationship

3.2.3. Air voids

The air void is one of the vital bituminous mixture parameters used for pavement design and the achievement of optimum asphalt content as in [1]-[9] and [11]. The volume of air voids is decreased with increasing of the plastic content as clear in Fig.9. This property is important for the pavements designed to serve in hot regions where the asphalt is suspected to flushing and bleeding where increased void ratio can be a solution for these problems and this as in [12].

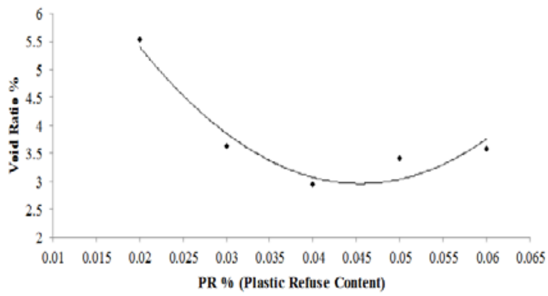

Fig.9 Air void values with varying plastic refuse content

3.2.4. Voids in mineral aggregate (VMA)

Voids in mineral aggregate (VMA) provide space for binder films on the aggregate particles .The durability of the mixture increases with the film thickness on the aggregate particles. In order to have the required durability of the mixture, minimum VMA requirements are recommended. Zoorab and Suparma in (2004) reported that the use of recycled plastics composed predominantly of polypropylene and low density polyethylene in plain bituminous concrete mixtures will increased durability and improved fatigue life. While, Zaniewski and Yan in 2013, concluded that a bleed down is observed when the asphalt flows off the aggregate while the sample is hotter. The VMA value versus (PR) for a percentage range of binder contents which is illustrated in Fig.10 below.

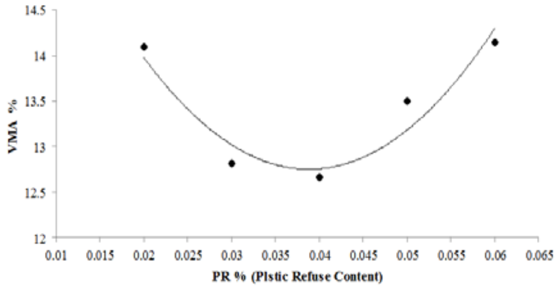

Fig.10 Voids in mineral aggregates –asphalt content relationship

As displayed in Fig.11, an increase in the PR causes the flow value to decrease slightly. As an elaborated in the last section, this result can contribute to the formation of a stiffer mixture. However, a high percentage of PR causes the flow to increase while the stability decreases.

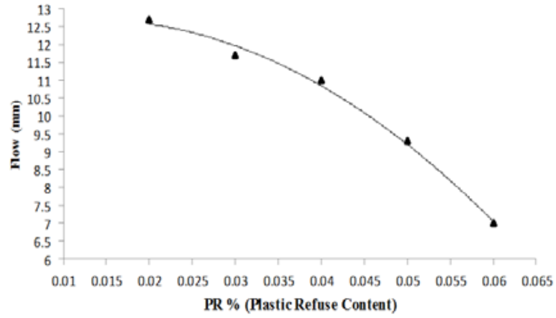

Fig.11 Flow values with varying plastic refuse content

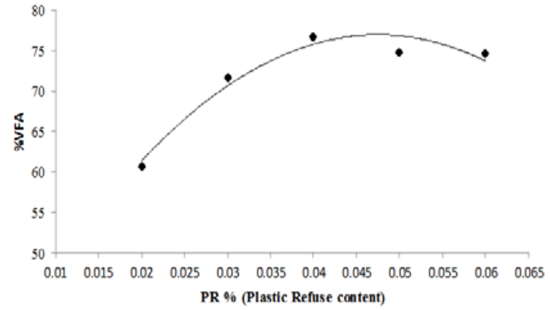

Fig.12 Voids percentage filled with asphalt - asphalt content relationship

Fig.12 shows that as the percentage of voids filled increases up to a point of 76 % the mixture of asphalt and refused plastic also increases up to 0.048 % of (PR), after which, the voids filled is decreasing as the PR content is increasing. This behavior may due to increase in stiffens of the sample after the ultimate value where the asphalt doesn't fill the voids.

3.3. **Part Three - Immersion time effect studies.**

This part of research shows the comparison between the properties of the conventional and modified asphalt mixtures for specimens under the effects of water immersion. Fig.13 shows that stability of the two specimens of the control mixture and PR mixture samples.

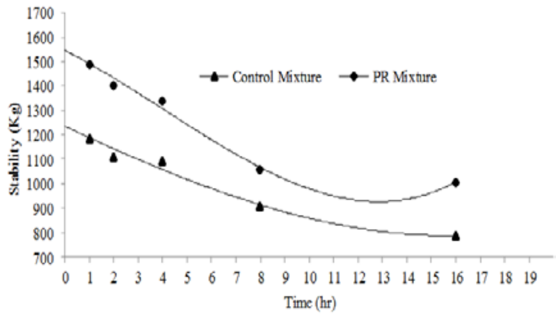

Fig.13 Stability of conventional (Control) and (PR) asphalt mixture

It is obvious from Fig.13 that as the time increase the stability decreases till it reach kind of constant value after 11 – 16 hours. This is because the grater the time of exposure, the oily material tends to evaporate and make the mix more stiff, till it reach a certain point then start gradually to collapse. So it is clearly that the flow property of samples mix with plastic refuse is better than the conventional and tends to maintain it properties as much as possible. This may be due to the effect of polypropylene (PE) additive in asphalt mixture which increases the adherent forces and homogeneity of mixture and aggregate. (PE) additive helps holding the oily material in the mix and maintain the properties of the mix.

On the other hand, Fig.14 shows the flow property for conventional (Control) and (PR) asphalt mixture samples. Results for different time are represented in Fig.14 below. It is clear that as the time increases the flow increases. This may be due to the fact that as submerge time of the specimen in water increases the adherent force between asphalt and aggregate decreases. This behavior may be due to the effects of water which removes the cover of asphalt film on the aggregate surfaces and water inters the aggregate's surface groves. As a results, this will damage and weak the asphalt mixture which increase the time of flow.

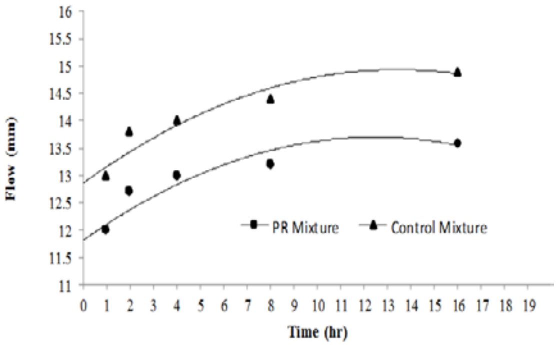

Fig.14 Flow with time of conventional (Control) and (PR) asphalt mixture

In general, flow can give an indication how much stiff the mix is, the mix with high flow value means that it is relatively weak. The relationship between flow and stability is negative the higher stability lesser flow and vice versa. Fig. 14 shows lower flow value at origin and starts increasing gradually as time elapsing.

4. CONCLUSION

It is concluded that an improvements of physical properties of propylene-asphalt mixture specimens in comparison with conventional asphalt specimens at optimum ratios had been deducted. The stability of conventional asphalt specimens was lower than the stability of (PR) asphalt mixture specimens. While the flow of (PR) asphalt mixture at optimum refused plastic with asphalt content of 4 % is decreasing with increasing PR content. Durability of PR mixture is increased with 43.75 percentage related to the value of conventional sample at 16 hours of testing time. Finally, flow of PR mixture is decreased with 10 percentage related to the value of conventional sample at 16 hours of testing time. Finally, it is clear that a significant improvement in stability and flow values are of 20 % increase in stability and 123 % decrease in flow values as shown in Figs.4 and 5 with Figs.7 and 11, this will help to develop a new generation of high performance paving products.

5. RECOMMENDATIONS

More investigations are recommended to carry further upon the materials used in this research to identify the engineering properties with using an alternative plastic types such as polypropylene. Conducting such research by using different types of aggregate and size distribution are useful for determination new and improved asphalt pavements mixtures.

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7. REFERENCES

[1] Ahmedzade, P., & Yilmaz, M., “Effect of polyester resin additive on the properties of asphalt binders and mixtures”. Construct Build Mater 2008;22:481–6.

[2] Chandra, K. Akisetty., Soon-Jae, Lee., & Serji, N. Amirkhanian, ” Effects of Compaction Temperature on Volumetric Properties of Rubberized Mixes Containing Warm-Mix Additives”. Journal of materials in civil engineering © ASCE / august 2009 / 409.

[3] Fontes, LPTL., Trichês, G., Pais, JC., & Pereira, PAA, “Evaluating permanent deformation in asphalt rubber mixtures”. Construct Build Mater 2010; 24: 1193 –200.

[4] George BS, “Evaluation of the Phillips Petroleum company’s product petromat”. Unpublished report; 1976.

[5] Huaxin, Chen., Qinwu, Xu., & Xi’an, “Experimental study of fibers in stabilizing and reinforcing asphalt binder”. Elsevier Ltd. All rights reserved, TX 78712, USA: 2009.

[6] Ismail, ZZ., & AL-Hashmi, EA, “Use of waste plastic in concrete mixture as aggregate replacement”. Waste Manage 2008;28:2041–7.

[7] John, P. Zaniewski., & Yu, Yan, “ Hot Mix Asphalt Concrete Density, Bulk Specific Gravity, and Permeability “. Asphalt Technology Program Department of Civil and Environmental Engineering Morgantown, West Virginia 2/1/2013

[8] Morozov, VA., Starov, DS., Shakhova, NM., & Kolobkov, VS, “Production of paving asphalts from high-wax crude oils”.Chem.Technol Fuels Oils 2004;4:23–6.

[9] National Asphalt Pavement Association (NAPA), “Designing and constructing SMA mixture. State of the Practice”. Quality Improvement Series 122- (2010).

[10] Putman, BJ., & Amirkhanian, SN, “Utilization of waster fibers in stone matrix mixtures”. Resource Conserve Recycling 2004;42:265–75.

[11] Sengoz, B., & Topal, A, “Minimum voids in mineral aggregate in hot-mix asphalt based on asphalt film thickness”. Build Environ 2007; 42:3629–35.

[12] Serkan & Tapkın, “The effect of polypropylene fibers on asphalt performance “. Civil Engineering Department, Faculty of

Engineering and Architecture, Anadolu University, 26555 Eskisehir, Turkey. 2007.
[13] Verma, S.S, “Roads from plastic waste “. Sant Longowal Institute of Engineering and Technology. The Indian Concrete Journal NOVEMBER 2008.
[14] Zorrob, S.E., Suparama, L.B, “Laboratory design and investigation of proportion of bituminous composite containing waste recycled plastics aggregate replacement (Plastiphalt)”. CIB Symposium on Construction and Environment Theory into Practice (2004).
[15] Tayfur, S., Ozen, H., & Aksoy, A, “Investigation of rutting performance of asphalt mixtures containing polymer modifiers”. Construct Build Mater 2007;27: 328–37.
[16] WSDOT FOP for AASHTO T 1661, “Bulk Specific Gravity of Compacted Hot Mix Asphalt Using Saturated Surface ‐ Dry Specimens”. WSDOT Materials Manual M 46-01.25, July (2016), pp 1 of 6.
[17] Xue, Y., Hou, H., Zhu, S., & Zha, J, “Utilization of municipal solid waste incineration ash in stone mastic asphalt mixture: pavement performance and environmental impact”. Construct Build Mater 209; 23:989–96.
[18] Zhang D, “Asphalt pavement”. 1st ed. Beijing: People’s Communication Press; 1999. United Nations Environment Programmer UNEP. (2009). “Converting Waste Plastics into a Resource”. Assessment Guidelines, (2009).
[19] United Nations Environment Programmer UNEP, “Converting Waste Plastics into a Resource”. Assessment Guidelines, (2009).