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Properties of Hot Mix Asphalt Containing Reclaimed Asphalt Pavement of the Aleppo highways

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ABSTRACT

The post-war phase requires engineers to prioritize and submit strategic plans for rebuilding the infrastructure destroyed by the recent war in Aleppo city, which has become an imperative, not an option. Roads and streets were also exposed to sabotage, as well as the lack of maintenance operations for these roads. In order to avoid the depletion of natural aggregates (NA), this research focused on the possibility of utilizing reclaimed asphalt pavement (RAP) as a raw material in the production of asphalt mixtures with specifications that dictate those made from natural materials. Furthermore, the unexpected increase in destructive highways is one of the environmental problems facing civil engineers in the future. Several percentages of pure asphalt were added to the RAP mixtures, which are as follows: 2, 2.5, 3, 3, 3.5, 4, 4.5, 5, 5.5, and 6% by asphalt mixture, where the ratio of pure asphalt 3%. The plastic waste (PW) was added to the RAP samples with ratios of 0, 2.5, 5, and 10% by pure asphalt weight. PW additives were of two types: polyethylene terephthalate (PET) and Polyvinyl chloride (PVC). The dry and wet mixing methods were used to add the PW to the RAP mixes. The study concluded that the percentage of rap added to the HMA samples is 50%, and the ratio of rap is 7.5%, according to the wet method. And that there is an increase in stability up to 25% when adding PVC to rap mixtures according to the wet method The replacement proportions of **RAP** were 0%, 25%, 50%, 75%and 100 % by total weight of HMA. Other alternatives should be considered.

Key words*:* Hot Mix Asphalt, Natural Aggregate, Reclaimed asphalt pavement.

1. INTRODUCTION

Asphalt concrete (AC) can be considered as a complex mixture that comprise of three constituents: aggregate that represent the main part, asphalt as the binder and air voids. In general, HMA is mainly composed of approximately 95% aggregates (coarse, fine and filler) and 5% asphalt cement [16]. HMA is usually made of dense graded that characterize the upper layer of asphalt highway pavement [27]. The paved surfaces cover a wide area of urban areas, where paved surface with bitumen concrete or Portland concrete cement can include up to 45% of an urban area in the United States [19].

Approximately two billion tons of NA are consumed in construction process each year in the US, this consumption is predicted to growth up to 2.5 billion tons per year by the year 2020 [22], [9], The latest studies have been stated that demolished construction amounts in the European Union (EU) around 850 million tons per year, this denote approximately 31% of the global waste generation [20]. The EU, 500 kg of rubble, demolished construction waste each year relate to every citizen [23]. On the other hand, the ground excavation to extract the aggregates production will cause environmental damage (the change of landscape) [10], [5]. The major source of raw aggregates which are used in the creation process of recycled aggregates are demolition of houses, residential buildings, bridges, roads, dams, and sometimes even from a natural disasters [7], [6].

The considerable quantities of reclaimed asphalt pavement (RAP) are produced annually from existing road pavement because of maintenance need to mill. After crushing and sieving analysis, the RAP can be recycled in new asphalt mixtures, where exact amount of virgin aggregates and asphalt cement. RAP considered a good reused material from both environmental and economic viewpoints [24].

The quantity of RAP depends on the properties and homogeneity of the materials involved in HMA mixes [18]. Several studies have shown that the optimal use of RAP ranges between 15 to 40 % in the HMA mixture, as the small percentage of RAP does not affect the properties of the mixtures. As for the high levels of it, there are many harms due to the excessive hardening of the asphalt, which leads to the appearance of premature cracks of low temperature and fatigue in addition to the oxidation during the working life of the pavement. This hardening can be explained by reducing the ratio of Maltenes in relation to the increase in Asphaltenes in the resulting mixture [1].

According to investigate on asphalt plants, adding of 30% of RAP mixtures into the HMA mixtures keep approximately 33% of virgin asphalt, where if the asphalt percent of original HMA are 5%, it needs 3.5% of virgin asphalt of the total mixes weight [24]. The effort in heating/drying RAP is one of

the main challenges to add RAP in HMA plant. Because of the moisture content and covered asphalt cement in RAP, addition high content of RAP regularly slows down HMA manufacture [13].

In the past, a main factors in the choice of the pavement type are performance evaluation and costs analysis. Recently, sustainable development may be considered most important factor [4]. Sustainability encompass three components are society, economy, and environment. A modern construction systems are often necessary to assess structure projects against the environmental, economic and social of sustainable development requirements [15], [12], [11]. A sustainable pavement can be defined a pavement that decreases environmental influences through the decline of energy and natural (raw) resources consumption and related emissions with the maintaining all performance and standards [17], [8].

One of the most important factors that leads to an increase in the area of landfills, is the increasing demand for plastic products and the resulting plastic waste (PW), which would cause significant damage to life on the planet as a material non-environmental. It is a non-degradable substance that causes damage to water, air and soil [25]. Reports indicate that the increase in the production of plastic between 1950 and 2015 reached 197 times, as it reached a quantity Plastic to 3.35×10^5 Kt. It is also expected that this percentage will double in the next twenty years, and the rate of increase may reach four times at 2050 [21]. The production of asphalt mixtures consumes large quantities of fuel, as it consumes heating and drying one ton of gravel for six liters in addition to emitting quantities of harmful gases to the environment [26].

Concerning the field examination of the possibility of using RAP in HMA mixtures, Ning lee et al. (2011)[24], performed their research by replacing 0, 10, 20, 30, and 40% of HMA components with RAP weight. They conclude that production of HMA with 30% RAP are similar to that of control HMA mixtures. Nonetheless, should be dried to 135 ^{O}C, since the RAP includes aged asphalt cement, and added aggregates should be dried to 140 ^{O}C - 170 OC. In addition the RAP and aggregates are mixed. Finally, and new asphalt is added into the RAP and aggregates. In contrast to the previous study, Valdés and other in 2011[14], were studied the possibility of adding high proportion of RAP to HMA, and then to illustrate the mechanical performance of asphalt mixtures. The results indicated that there is a possibility of using RAP up to 60% in HMA mixture, where HMA-RAP mixes could work in a comparable manner to that of high modulus of HMA mixture.

Another conclusion about the use of RAP has been made by Hussaina and Yanjunaand in 2013[3], they has studied the properties of residual binder is extracted from RAP as well the virgin binder properties. It was stated that, with the increase in the amount of RAP, the stiffness of the asphalt bond, viscosity and temperature of the mix increases.

Regarding adding PW to RAP mixtures, Leng et al. 2018[28], determine the proportion of PW used to produce the modified mixes by RAP. They have used two specimens: Fist, virgin asphalt to make control HMA mixes (reference mixes); second, modified asphalt with 2% PW was prepared and then modified asphalt added to 15, 25 and 40% RAP mixes, where the mixing temperature was 150 ^{O}C. The results specified that the mixes comprising PW and RAP providing improved performance related to the reference mixes. As experiments also showed that the resistance of fatigue cracks increased by 60% in addition to increase rutting resistance by 15% from the reference mixes. This study also concluded that the use of RAP and PW enhances the performance of prepared mixtures against low temperatures.

As for recent experiences on the RAP it has been made by the group of researchers, Jamshidi et al, 2019 [2]. They studied the effect of the RAP source and its quantity on the properties of asphalt mixtures, the dynamic modulus. An analysis of the outcomes showed that the dynamic modulus of RAP were 6.8 to 12% greater than the conventional specimens, this indicates that RAP is less susceptible to temperature.

2. RESEARCH GOALS

From the summary of previous studies and the current situation of the Aleppo city, as it emerged from a war that affected in general the infrastructure and in particular on the various highways of the city. And the resulting rubble of destroyed buildings and highways hat must be used as a recycled construction material. Which requires the removal of some of the surface layers of the highway, and this leads to large quantities of RAP material. The aim of this research is to highlight the engineering properties of the RAP mixtures in addition to the possibility of using PW as a modifier to the RAP mixtures. Some destroyed highways in the city of Aleppo have been chosen RAP extracted from them as a case study.

3. METHODOLOGY

Several mixtures of modified HMA (MHMA) were designed with different proportions of RAP of mixtures weight, and the replacement ratio respectively: 0, 25, 50, 75, and 100%. The specified aggregate gradation according to Syrian specification of the mixtures has been taken into consideration as shown in the table 1, so that the natural limestone aggregates were mostly from the coarse aggregates, because the RAP aggregates were passing from sieve # 12.5 mm. Therefore, the natural coarse aggregates were combined with fine RAP to produce as homogeneous mixture as possible that met the required specifications.

Initially 15 samples were prepared from mixtures by adding a fixed percentage of pure asphalt which is 3% with all ratios of the previous RAP to determine the behavioral difference. Where a percentage of 3% was chosen according to several investigations as showed in table 2. This has been observed that with an increase in the percentage of RAP in

mixtures, asphalt bleeding occurs from the sample when asphalt ratios increase. This is normal because the RAP already contains a significant amount of asphalt, the number of samples was 54 determine the percentage of asphalt (3%).

After that, work was done to determine the optimum ratio of RAP for each mixture of mixtures according to the Marshall method. In order to calculate the ratio of voids (V_a) in the modified mixtures with RAP, the specific gravity (G_{mb}) of these modified mixtures was calculated, and then the G_m of the RAP aggregates determined after the old asphalt was separated using a solvent and then the aggregates were washed with a detergent liquid so that old asphalt are disposed of and then its weight. This method is considered acceptable to some extent, as this method was calibrated by assuming the same G_m, since the RAP aggregates is also limestone, with the calculation of the percentage of old asphalt in it, a great convergence between the two results was observed.

The final step was to make the MHMA with PW according to the dry and wet method. The wet method, a pure asphalt heated around 105 ^oC to be transformed to liquid form and then PW frequently added into pure asphalt, where the temperature should remain between 160 and 170 ^oC to avoid thermal damage to the PW. To ensure the desired consistency is achieved, a slow, uniform mixture should be stirred. PW was added at 0, 2.5, 5, 7.5, and 10% of 3% pure asphalt. The modified asphalt was added to cover the hot aggregate to sure regularly dispersion over aggregates. PW was of PET type, and it was cut into sizes from 1 to 4 mm.

As for the dry method, PW is added directly to hot natural aggregates (around 160°C-170°C). The hot aggregates combined with the PW to achieve a uniform spreading of PW over aggregates. Finally, the aggregates surface covered with PW is produced, and after sleep has cooled down with pure asphalt mixture, and after it cools, it is mixed with pure asphalt (3%). PW was of PVC type, and it also was cut into sizes from 1 to 4 mm. The sample numbers to determine the optimum content of PW were 30 (15 dry method, 15 wet method).

Table 1: Aggregate Gradation

Sieve opening	**% Percentage of passage**
19 mm	100
12.5 mm	75-90
9.5 mm	64-79
4.75 mm	41-56
2 mm	23-37
0,425 mm	7-20
0,180 mm	5-13
0,075 mm	3-8

Table 2: shows the composition of the mixtures and their basic characteristics

Mix class	Asphalt Ratio %	Asphalt Weight Kg	Natural Aggregate Kg	RAP %	G_{mb}	MS Kg	Flow mm	Va %
0% RAP	3.0%	36	1164	0	2.25	1035.5	3.29	9.80
	5.0%	60	1140	0	2.28	1161.5	3.51	5.58
	5.5%	66	1134	0	2.29	1231.5	3.65	4.42
	6.0%	72	1128	0	2.28	1136.5	3.93	4.07
25% RAP	3.0%	36	873	291	2.28	1079.5	3.50	7.05
	5.0%	60	855	285	2.31	1084.5	3.68	2.70
	5.5%	66	851	284	2.31	1066.5	3.93	2.08
	6.0%	72	846	282	2.30	977	4.15	1.75
50% RAP	3.0%	36	582	582	2.30	1117	3.54	4.82
	4.0%	48	576	576	2.32	1129	3.62	2.34
	4.5%	54	573	573	2.33	1166	3.80	1.28
	5.0%	60	570	570	2.32	1182.5	4.02	0.93
75% RAP	3.0%	36	291	873	2.30	1112	3.74	3.22
	3.5%	42	290	869	2.31	1161.5	3.92	2.16
	4.0%	48	288	864	2.29	1077	4.13	2.35
100 % RAP	2.0%	24	0	1176	2.28	1037	3.84	4.15
	2.5%	30	0	1170	2.29	1076	4.12	3.23
	3.0%	36	0	1164	2.30	1106	4.28	1.95

4. RESULTS AND DISCUSSION

4.1 Determine the Optimum Asphalt Proportion

The pure asphalt used in the search was a 60/70 penetration degree, based on the environmental conditions of Aleppo city and the ratio of adding the asphalt to the mixture was as follows 3, 5, 5.5, and 6% by mix weight to prepare a reference mixtures. The optimal asphalt ratio (OAR) was 5%, as showed in table 1. The RAP samples were prepared at an OAC of 3 % by total weight of HMA. The next stage was to choose the OAR suitable for the RAP mixture, as different ratios of asphalt 2, 3, 4, 5. 5, 5 and 6% by mix weight were adopted in addition to various ratios of RAP 0, 25, 50, 75, and100%. By collecting the data from Table 2 for the stability, the voids ratio and the specific gravity, a ratio of 3% asphalt can be adopted to add to the RAP mixtures.

4.1 Determine the Optimum RAP Proportion

The results display that as the RAP ratio increase the Stability decreases, as shown in Figure. 1. This can be explained by the fact that RAP aggregates have weaker properties than normal aggregates. In addition to increasing

the percentage of asphalt present in the RAP, which has an effect on increasing the spacing of the aggregates from each other.

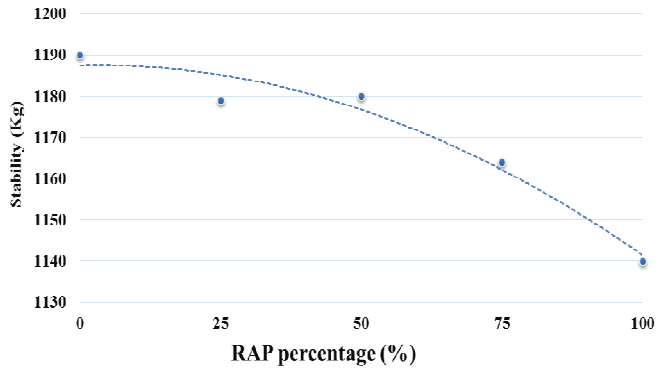

Figure. 1: Stability versus RAP Ratio

As the ratio of RAP, rising began the specific gravity curve to rise until it reaches the maximum value, and then began to decline slightly as shown in Figure. 2. This increase is related to the increase in the external specific surface of the RAP aggregates in HMA, this portions have higher old asphalt than the natural aggregates.

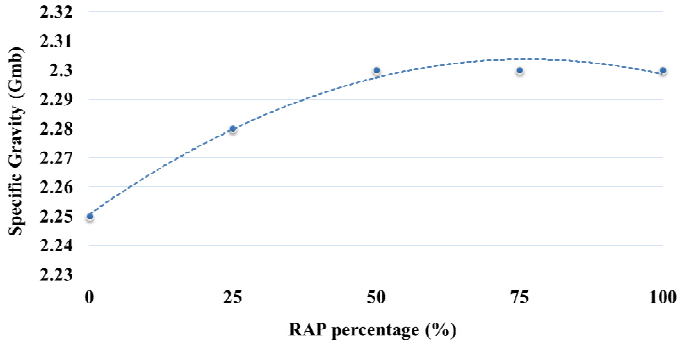

Figure. 2: Specific gravity versus RAP Ratio

The void ratios (V_a) decrease as RAP ratio increase as revealed in Figure. 3. This is due to the increase in the percentage of asphalt in the RAP, which reduces the V_a in the HMA. As for the anomalous point at 25% of the RAP, it returns to the fact that the ratio of the added asphalt (3%) and the asphalt present in the RAP is still a slight percentage of the optimal ratios and therefore gives a greater V_a.

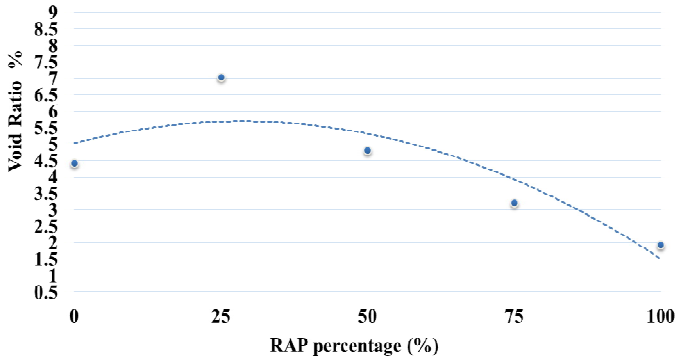

Figure. 3: V_a versus RAP Ratio

The high stability value corresponds to a low flow value and vice versa [12]. As presented in Figure. 4, an increase in the RAP ratio cause the flow to increase, this performance may be attributed to the high asphalt percentage.

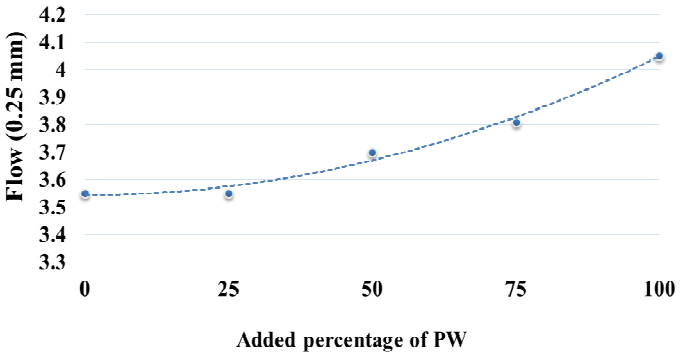

Figure. 4: Flow versus RAP Ratio

In relation to the maximum stability and the higher value of specific gravity in addition the allowed V_a (3-5%, usually 4%) [28], the optimum RAP ratio are 50%.

4.2 Determine the Optimum PW Proportion

After the adoption of each of the 3% asphalt (as an addition to RAP mixtures weight) and the ratio of the RAP by 50% of the weight of the asphalt mixtures. The last stage of the research began by adding PW to the RAP mixtures, according to the wet and dry method of PET and the wet method of PVC. The specific gravity values gradually drops as the PET and PVC proportion increases for the wet and dry method, as revealed in Figure. 5. This gradual decline could be due to the formation of slight crystal of the PW in the mixture of HMA. Certainly, the specific gravity of PW for smaller parts of PW is less than the weight of aggregates.

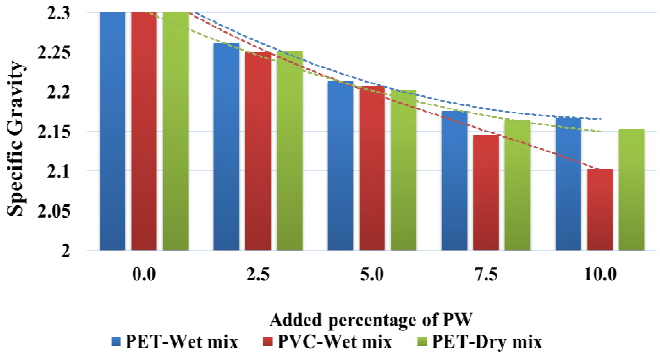

Figure. 5: Specific gravity versus PET and PVC Ratios

Increasing the proportion of PW leads to gradual increase in stability up to 7.5% of PET and PVC as indicated in Figure. 6. And then it differences to a descending movement. The developed performance of mixes may be illuminated by the

increase in the proportion of PET and PVC. In general, the PW have better adhesion property between the aggregates. And after this result, any increase in PET and PVC result in a reduction in the stability, this is associated to the development of a harder mixture was formed from the small, crystallized parts of the PET and PVC.

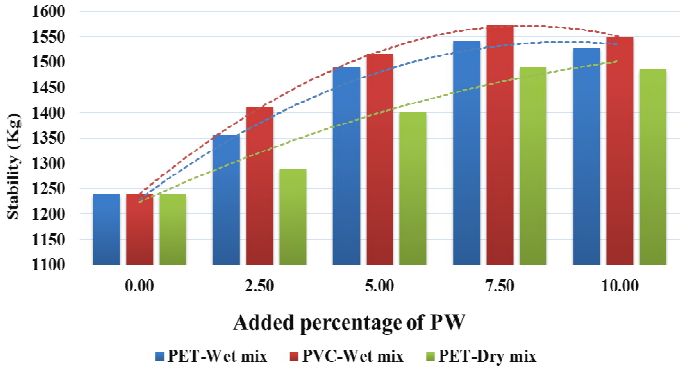

Figure. 6: Stability versus PET and PVC contents

As shown in Figure 7, the increase in the ratio of PET and PVC leads to a decrease in flow value, and this behavior may be due to the formation of a more hard.

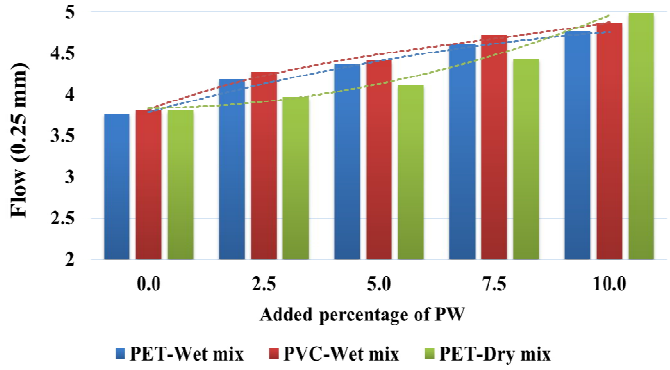

Figure. 7: Stability versus PET and PVC contents

Optimum ratio of the admixtures are found to be 7.5% for each the PET and PVC of asphalt ratio, where all of Marshal Stability values are developed better. But Stabilities of MHMA with PVC have a higher value of PET. It can be concluded that the dry method of mixing the PET does not yield meaningful results.

4. CONCLUSION

In this investigation, engineering characteristics of asphalt mixes made by 3% of pure asphalt and 50% RAP were defined and can be brief those outcomes over the following.

1. 3% pure asphalt (from the total sample weight) is the optimum and acceptable percentage for adding RAP mixtures.
2. The optimum RAP ratio was 50% of the weight of the HMA mixtures.
3. A 7.5% of PET or 7.5% PVC of pure asphalt are optimum ratios of PW according to wet mix method.
4. The addition of PET to HMA mixes according to the dry method of mixing does not yield meaningful results.
5. Addition of PET-wet method to RAP mixes gives an increase in stability approximately 25% with respect to reference samples,
6. The dry method is the optimum mixing method, as it has greater stability values than the dry method for the PET.

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