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The Potential use of Crumb Rubber in Hot Asphalt Mixes in Egypt using Dry Process

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Abstract: Since 1960 Using crumb rubber modifier (CRM) in hot asphalt mixtures has become a frequent practice in road construction. Using the CRM by the dry process method is not commonly used, although it has great advantages such as it is less fuel consuming and it does not require storage container like the wet process method. This research evaluates the mechanical properties of dense graded asphalt rubber mixtures manufactured using the dry process. The results obtained from this mixture compared with similar asphalt mixture without CRM. The mechanical properties of all mixtures evaluated using a set of tests such Marshall Stability and flow test, moisture susceptibility test, indirect tensile strength test, dynamic modulus and flow number test. The research results showed that using CRM with 0.75% of aggregate's weight increased the mixture's stability, flow and enhanced its cracking and permanent deformation resistance.

Index terms: *crumb rubber, dry process, hot asphalt mixture, marshal stability and flow.*

I. INTRODUCTION

Over the last 5 decades, using crumb rubber extracted from end life tires has become a common practice in road construction [1-5]. Many researches proved that using CRM rubber with different asphalt mixtures could modify its mechanical properties like increasing rutting resistance, crack resistance and thermal susceptibility [6]-[7]. The main source of Crumb rubber is end life tires [6]. The main components of Tires are natural, synthetic rubber and carbon black [8]. Long time ago, there were some variations in portions of tires between different types of tires specially trucks and passenger cars. However recently there is little difference between them [8]. There are slight variances in the percentage of natural and synthetic rubber that believed to have no significant effect when used as an additive in HMA [8]. There are two main methods used to reduce the crumb rubber size for asphalt modification ambient grinding and cryogenic fracturing [1]-[8].

The cryogenic fracturing involves some successive steps the first one is separate the steel belting and cutting the larger tire using sharp steel cutters into 5 cm particles, which then be frozen using nitrogen liquid and then be fractured, Producing a different sizes from, passing the 75 µm sieve, to 5 mm size particles. These fractures have cubical with a smooth surface. The ambient grinding method has the same initial steps just like the cryogenic process, but not using nitrogen liquid to minimize crumb rubber to the required sizes and using sharp blades. The smaller particles are then passed through shredders that grind remaining parts into smaller particles. The ambient grinding also produce sizes ranging from passing the 75 µm sieve, to 5 mm size particles [1]-[8]. The main difference between these previously mentioned two methods are the surface texture of the rubber particles that ambient grinding produces a rough texture with increased surface area which formed by the grinding process [8].

Since 1960, rubber recycled from waste tires has been used in modification of HMA. The use of rubber in asphalt materials started because of getting benefit from the elastic properties of crumb rubber which had the potential to enhance the skid resistance and durability of HMA dynamic load resistance [1].

Charles McDonald, Materials Engineer for the City of Phoenix, Arizona, developed a method of using crumb rubber in modification of the bitumen by adding fine crumb rubber particles (about 20% of bitumen content) directly to the bitumen and keeping them both in a temperature from 170 to 200 Celsius and adding this rubberized bitumen to the aggregate this method called wet process [8].

Since 1970, Dry mixed rubberized asphalt mixture was developed in Sweden, where large rubber particles were used in asphalt pavement mixtures as a substitution of a small percentage of aggregate; the main concept was to increase skid resistance and enhance pavement durability [1].

There are two techniques for using CRM as an additive for HMA; the first one is the 'wet process', in which fine rubber blended with hot bitumen to produce a 'rubberized bitumen; the second method is the 'dry process' which substitutes a small portion of the mix aggregate with crumb rubber, causing the rubber to function essentially as an elastic aggregate within the mixture [1]-[2]-[7]-[9].

In this research, any mention of a rubber modified asphalt mixture or 'CRM mixture' is made using the dry process. Until recently, the design of CRM mixtures using dry process has been used without any specifications or official standard documentations. There are three general mixture gradation types used with CRM asphalt pavements; open graded mixtures, gap graded mixtures and dense graded mixtures [1]. Open and gap graded mixtures are the most frequently used mixtures with CRM because they got enough spaces between aggregate particle for the crumb rubber [1].

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CRM used in dense-graded mixtures will typically be a system that uses a very fine particulate rubber with size ranges from 0 to 0.6 mm [10].

In the dense graded mixture, the aggregate gradation must be on the coarser side of the specification to provide enough spaces for the crumb rubber [8].

The main modification concept of dry process crumb rubber asphalt is based on two reasons; the first one is using crumb rubber as an additive to substitute a small portion of aggregates with rubber; as the rubber has a great elastic behavior that can resist static and dynamic loads and get back to its original shapes after releasing these loads [1].

The second reason is the interaction between crumb rubber particles and bitumen, this reason considered as the main reason for modification for both wet and dry process [1]-[10]-[11].

II. MATERIALS

A. Aggregates

The used aggregate in this study was dolomitic limestone brought from 101 armed forces crusher located on Suez road The reason for using this aggregate because it is the most usable aggregate in Egypt.

Two types of aggregate used in this study (coarse &fine) aggregate.

The coarse aggregate consists of two sizes the coarse aggregate (Pin 1 and Pin 2) and the fine aggregate consists of both natural sand and crushed sand. Also mineral filler was used in order to fulfill the required gradation for the mixtures.

Table1 represents the gradations for the previously mentioned aggregates.

Table 1: The aggregate gradation of different aggregate sizes

Sieve size	Percent passing%				
	Pin1	Pin2	Crushed sand	Mineral filler	Natural sand
#1	100	100	100	100	100
#3/4	100	65	100	100	100
#3/8	66	5	100	100	100
#4	1.4	1.7	92	100	100
#8	1.1	0.3	61	100	98
#30	0.7	0.3	25	100	65
#50	0.4	0.3	13	98.8	30.5
#80	0.4	0.3	6	96	10
#100	0.2	0.3	5.3	93.8	1.1
#200	0.2	0.3	2	77.6	0.3

B. Crumb rubber

The crumb rubber used in this study brought from as factory in 15 may city, Cairo, Egypt.

This crumb rubber brought to this factory from Meet Elharon – Elgharbya after going through successive processes of grinding shredding, etc. Table 2 represents the gradations for the used crumb rubber.

Table 2: Crumb rubber gradations

Sieve size	Passing percent%
#1	100.0
#3/4	100.0
#3/8	100
#4	100
#8	100
#30	99.6
#50	76
#80	53
#100	3.2
#200	0.1

C. Bitumen

The bitumen used is 60/70 penetration graded because it is the most frequent bitumen type in Egypt. It brought Asphalt binder used in this study is a 60/70 penetration graded bitumen, which is the most used in Egypt. It was collected from Alexandria.

The bitumen also subjected to some validation tests to ensure that it can be used as a pavement material.

These tests were penetration test, softening point test and rotational viscosity test, specific gravity.

Table 3 represents the results of these tests.

Table 3: validation tests results of bitumen

Test	Standard	Value		Egyptian code limitations	
Penetration Test (25°C)	ASTM D5	66		60	70
Softening Point	ASTM D36	48		45	55
Rotational Viscosity at 135°C	ASTM D 4402	395		320	--

III. EXPERIMENTAL PLAN

This study will focuses on the hot mix asphalt mixture called 4-C because this is the most usable surface layer in most Egyptian national roads according to the Egyptian code of practice (ECP 2017). This study aims to study the potential use of crumb rubber in hot asphalt mixtures in Egypt as a substitution of a small part of the fine aggregate in the hot asphalt mixture for the mentioned before asphalt mixtures. A control mix of 4-C mixture will be designed and prepared containing 0% CRM to be used as a reference to evaluate the results from adding to CRM to the same hot asphalt mixture. Six different mixtures prepared with different CRM percentage. Those percentages were 0%CRM (the control mix), 0.25% CRM, 0.5% CRM, 0.75% CRM, 1% CRM and 1.5%CRM. These mixtures designed and tested with specific procedures. It is very important to be mentioned that CRM is used as a replacement for an equivalent sizes from the mixture's aggregate as mentioned in many research studied.

Mixtures in this research were subjected to a set of performance indicator tests such as Marshall Stability& Flow test. Loss of stability test also used to investigate the moisture susceptibility of these mixtures.Indirect tensile strength test is also performed on all mixtures to investigate their cracking and permanent deformation resistance. In the end the dynamic modulus and flow number tests the UTM machine were performed to chick their performance under different traffic loading, weather conditions and rutting resistance.

IV. RESULTS AND DISCUSSION

A. The control mix design procedures.

As mentioned before, using the crumb rubber as a modifier with dense graded mixtures will require that the aggregate gradation must be on the coarser side of the specification to provide enough spaces for rubber.

Figure 1 represent the lower and upper limits for 4-C mix and the aggregate gradations used in the control mix. Table 4 represents Marshall Design values for control 4-C mix.

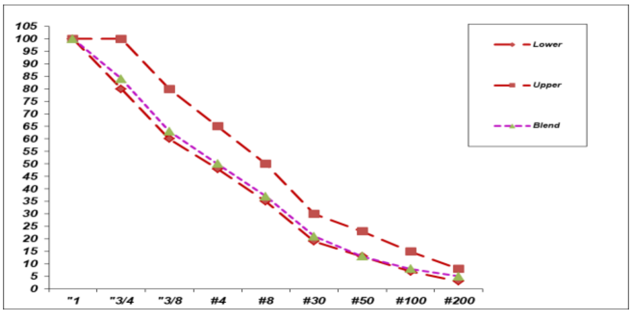

Figure 1: aggregate gradation for the control mix

Table 4: Marshal Mix design values and volumetric values for the control mix.

Property	Marshall design result
Optimum asphalt content (%)	5.40%
Mix bulk specific gravity (g/cm3)	2.33
Air void (%)	3.319%
Voids in mineral aggregate (%)	15%
Marshall stability (Kg)	1320
Flow (mm)	3.3

B. Mixtures performance tests

This part will discuss different tests results to measure different mixtures performance.

1. Marshal Stability &flow test results

Figure2 represents the marshal stability test results and it was noticeable that increasing CRM percentage increases

The asphalt mixture's stability until it reaches 1% CRM stability starts to decrease and that happened because as the percentage of CRM exceed a certain limit the rubber particles will resist the compaction effort used to prepare the specimen and there will be some compaction issues in this mixture so it is obvious that CRM percentages should not exceed 1% of aggregate weight.

It's also noticeable that 0.75% CRM has the best stability results.

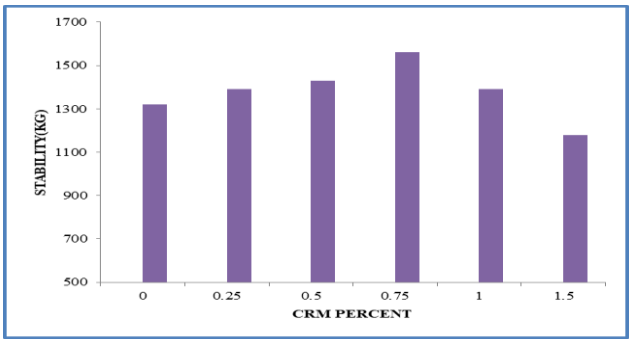

Figure 2: stability Vs. CRM% results

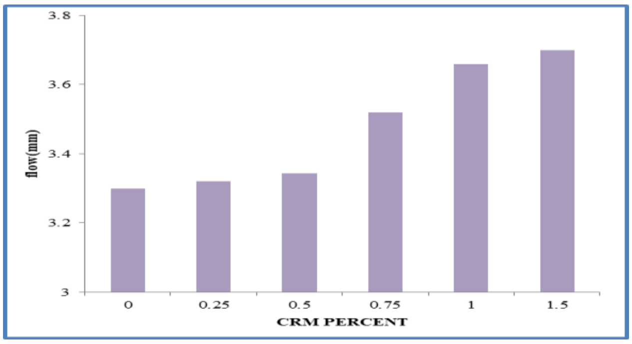

Figure 3: Flow Vs. CRM% results

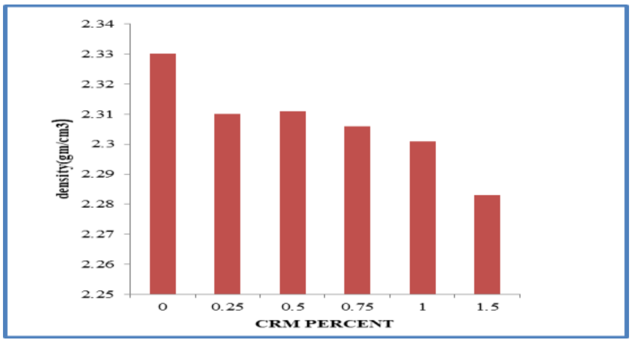

Figure 4: density Vs. CRM% results

Figure (3&4) shows that as the CRM percent increases the flow of the asphalt mixtures and its ability to resist deformations increases and also it was obvious that as CRM percent increases the density of the asphalt mixture decreases.

2. In-direct tensile strength

Figure 5 represents the test results of the indirect tensile strength Vs. different CRM percentages 'it is clear that CRM mixtures have a higher results than the control mix until it reaches more than 1% CRM, also it is noticeable that also 0.75% has the best results which indicates that it has a better cracking, permanent deformation resistance.

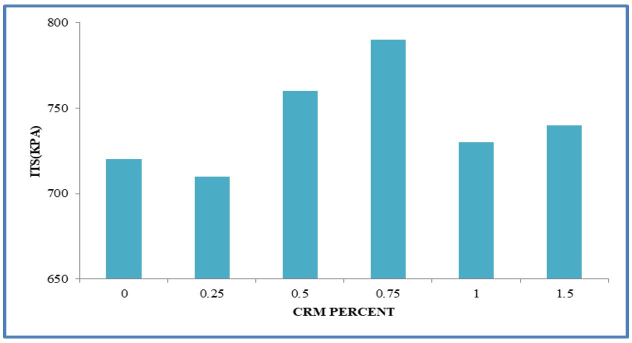

Figure 5: In-direct tensile strength Vs. CRM% results

3. Moisture susceptibility

Using loss of stability test can evaluate the moisture damage of the hot asphalt mixtures. Figure 6 represents a comparison between loss of stability percent Vs. CRM percent for all previously mentioned mixtures.

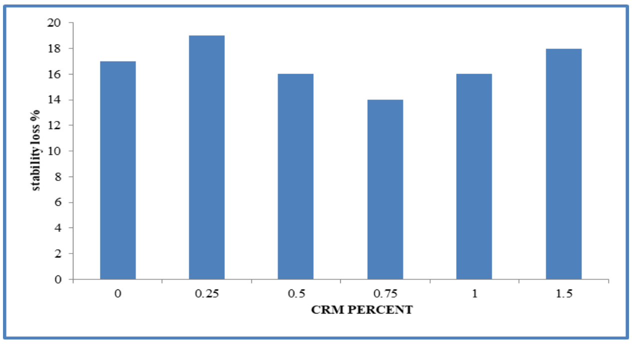

Figure 6: loss of stability percentage Vs. CRM%

From the previous figures it is noticeable that the loss of stability doesn't change significantly by adding CRM.

4. *Dynamic modulus test*

For each mixture two replicates are tested and the dynamic modulus for each one is calculated at different frequencies (0.1, 0.5,1,5,10 and25) Hz. at different temperatures as per AASHTO TP62. Then the master curve is drawn at 21.1 °C (70 Fahrenheit) by shifting other curves for other temperatures

The next figures (7-11) represent the master curves of different CRM percentages.

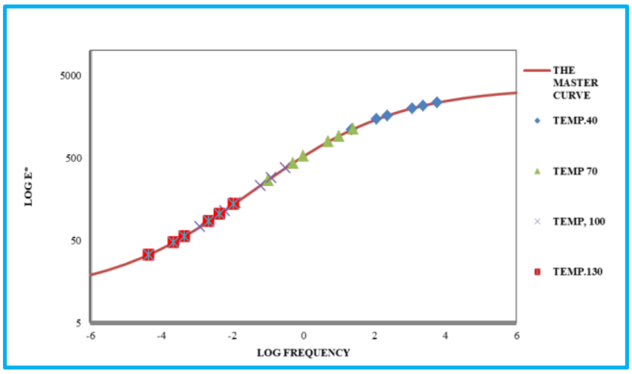

Figure 7: master curve for the control mix

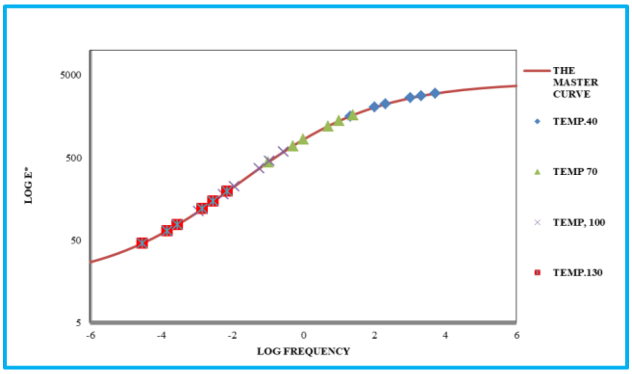

Figure 8: master curve for the 0.25% CRM

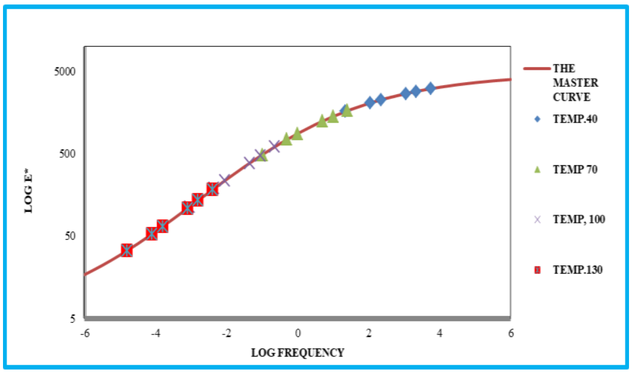

Figure 9: master curve for the 0.5% CRM

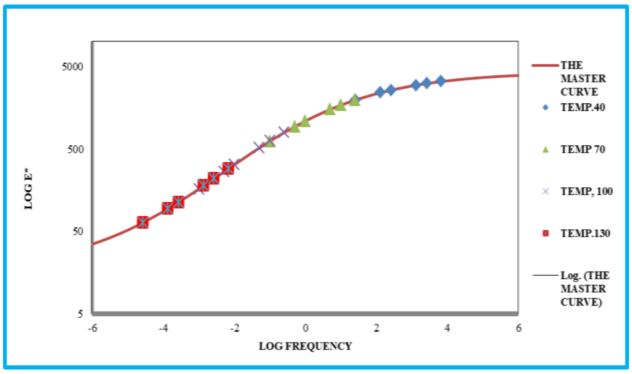

Figure 10: master curve for the 0.75% CRM

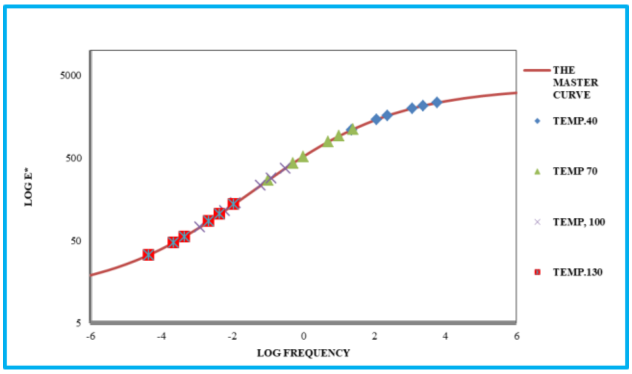

Figure 11: master curve for the 1% CRM.

Figure 12 shows a comparison between dynamic modulus master curves for different CRM percentages.

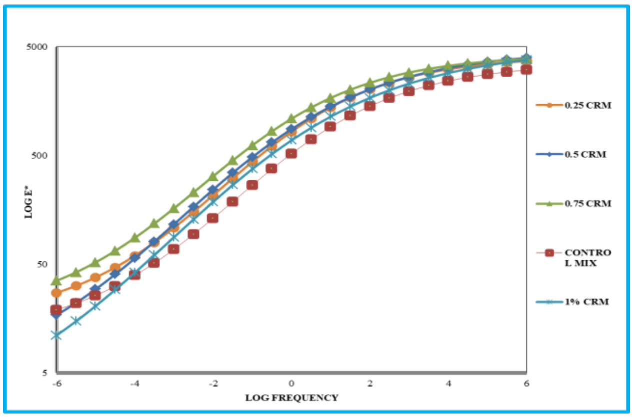

Figure 12: master curves for different CRM percentages.

As shown in the previous figure the mixtures with 0.75 percent has the highest dynamic modulus (E*) and also has the best results, especially in hot temperatures that indicates that it has the best rutting resistance in comparison with the other asphalt mixtures.

V. CONCLUSION

According to the previously mentioned results of this research the following conclusion can be conducted:

1) It was obvious that using crumb rubber as an additive for hot asphalt mixtures increased their stability and indirect tensile strength values the optimum CRM percentage was 0.75%.
2) The percentages more than 1% CRM showed compaction problems in comparison to (0.25%, 0.5% and 0.75%) percentages.
3) Adding crumb rubber to the mixture did not show any significant results to moisture susceptibility.
4) Adding crumb rubber to hot asphalt mixtures showed a great improvement in rutting crack resistance of asphalt.
5) Adding crumb rubber to hot asphalt mixtures showed a great improvement in rutting crack resistance of asphalt.

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