INVESTIGATION OF THE IMPACT OF RAP GRADATION ON THE EFFECTIVE BINDER CONTENT IN HOT MIX ASPHALT

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ABSTRACT

Nowadays, it is common to add a little amount of Reclaimed Asphalt Pavement (RAP) in asphalt mixes without changing too much properties such as modulus and low temperature cracking resistance. Not only will those mixes be able to make roads last longer, but they will be a greener alternative to usual mixes. In order to make a flexible pavement design, the mixture behavior is usually characterized with the complex modulus. To have a high modulus mix, you need to control the gradation precisely even when RAP is added. When performing a mix design to incorporate RAP, it is desirable to know the RAP binder characteristics and content and its gradation. In the literature, there is no clear vision of the RAP gradation impacts on the mixture properties and field performance. The objective of this study, performed at the Pavements and Bituminous Materials Laboratory (LCMB), is to evaluate the impact of RAP gradation on Hot Mix Asphalt. This is needed to understand how much binder can be transferred during mix from RAP to virgin aggregate. In this study, a single source of RAP was separated into different sizes and mixed with a specific group of virgin aggregates. Then, according to their size, the mixes were separated again into the RAP group and virgin aggregate. While these were mixed, active RAP binder transferred to virgin aggregate. Then ignition test (ASTM D6307) was adapted to separate RAP binder from virgin aggregate. With this procedure, it was possible to see that, for a given temperature and mixing time, activated binder amount of coarse RAP particles and fine RAP particles. The Ignition test result showed that coarse RAP particles have more active binder in mix but ITS test indicated that fine RAP particles have higher strength.

Keywords: Hot Mix Asphalt, Recycled asphalt, RAP gradation, IDT, Ignition test

1. INTRODUCTION

Nowadays, it is common to add a little amount of Reclaimed Asphalt Pavement (RAP) in asphalt mixes without changing too much the properties such as modulus and low temperature cracking resistance. Not only will those mixes be able to make roads last longer, but they will be a greener alternative to usual mixes a reusable mixture of aggregate and asphalt binder can be a worth approach for technical, economical, and environmental reasons. RAP that is consisting of aged binder and aggregate particles provides saving energy, according to the various RAP content with considering the total cost(Kandhal & Mallick, 1998)

Despite the fact that there is no recognized limit of the amount of RAP that can be added to any mixes, it has been limited by many agencies and it varies from 10 to 50%. In 1997, the Federal Highway Administration's RAP expert task force developed guidelines for the design of superpave HMA containing RAP (Bukowski, 1997). These guidelines have been supported by the findings of the NCHRP research report 9-12 (R. S. McDaniel, Soleymani, Anderson, Turner, & Peterson, 2000). But there is no clear vision of how it can be added to the mix and what conditions are needed to prepare RAP before mixing. The level of interaction between old and new materials is a major factor that is still unclear. Different scenarios can be developed such as; there is no interaction so RAP can be called Black Rock, it means that it does not significantly change the virgin binder properties. But with heating there is the possibility that the RAP binder can change the rheological properties of the mix. However, there is no specific method to see how it works. In fact, many design procedures prefer to assume that all the aged binder is fully available and can be mixed with virgin binder and would effectively contribute to the blend. The Full amount of RAP binder can reduce the needed total amount of virgin binder.

When RAP is used, many mix design factors like mix duration, mix temperature, RAP and aggregate surface area, etc., can influence the rheological properties of the mix.   Because of this, it is important to characterize each part of the RAP precisely. Since aggregates account for more than 90% by volume of the mixture, each particle has a great impact on RAP binder absorption. This study is going to characterize the impact of each particle with respect to the active binder that can cover the virgin aggregates.

In this research, the amount of RAP binder that can be mobilized from RAP aggregate to virgin aggregate during construction was analyzed. In fact, the impact of virgin aggregate size on RAP binder mobilization was investigated.

2. BACKGROUND

Milled pavements can be considered as a valuable material after they reached the end of their service life. Reclaimed Asphalt Pavement (RAP) can be added to virgin Hot Mix Asphalt (HMA) in order to conserve materials and energy. However, it is necessary to account for old materials in the HMA design process. The rheological properties of asphalt continuously change during the road service life and it would not be the same as virgin materials, but at least RAP can act like virgin materials, it can even improve the performance of new pavements. Since past decades, several studies have been done to characterize the RAP and use it as proper way in mixture.

At the beginning of the implementation of RAP, there were no guidance of how to integrate RAP into a new mix design, but based on experimental research, interim recommendations were defined through the FHWA Asphalt Mixture Expert Task Group (Bukowski, 1997). Afterwards, according to the performance of Marshall's mixes with RAP, new specifications were developed in 2002 and it has been available in the Superpave system. In addition, AASHTO Standards MP2 (now M323), standard specification for Super-pave volumetric mix design for hot mix asphalt, describe how to design HMA with RAP (Basueny et al., 2013).

Since aged binder and aggregates are included in RAP, mix temperature, mix duration, aggregate gradation, and preheating conditions can change the performance of the new mix. Europe standard method EN 12697-35 presented a method of how to prepare RAP materials to add to the mixture. It can be added in a different manner like cold, heated in a microwave, heated in an oven in a covered pan, and heated in an oven in a non-covered pan. The preheating condition impact would be change according to the changing the amount of RAP in the mix. Basueny et al., (2013) showed that they cannot propose a specific method from the four methods to be used in the laboratory since each method has its advantage and disadvantages from the degree of handling and the required time saving.

With respect to the different conditions and mix durations and temperatures, the reaction between the RAP and the other components could change. Achieving at least the same performance level of HMA without RAP is the critical aspect to reuse asphalt. Several researches have been done to understand the properties of mixtures with inclusion of RAP. One of the main concerns is the degree of interaction of old materials with new one, and the behavior of RAP during a new mixing procedure according to different percentages of RAP. Since a correlation was found between microstructural characteristics and mechanical properties (Nahar et al., 2013) it becomes important to develop a deep understanding of the physical phenomena occurring during a new fabrication as well as the definition of the degree of blending to determine the rheology of the final binder (Booshehrian et al., 2012).

The interaction degree is a serious concern that directly affects the performance of HMA that incorporates RAP. The level of blending affects both the performance of the produced HMA and the economic competitiveness of the recycling process. It can be assumed that RAP totally participate in the mix when it is actually behaving as a black rock, or it can be assumed that RAP binder does not blend with the virgin binder when there is some evidence that it does and finally, the complicated assumption is that the blending process may take some time to occur and is influenced by various factors (Carpenter & Wolosick, 1980). There are various possibilities according to utilize RAP in mix. It can act as a black rock; it means RAP binder has no impact on mix. Black rock in NCHRP 9-12 were fabricated by extracting binder from RAP afterward RAP aggregate can be added to mix. Another possibility is that RAP completely participates in mix so RAP binder blends with virgin binder as well as RAP aggregate blends with virgin aggregate. Third one called practical blended which is blending unprocessed RAP with virgin material. The NCHRP 9-12 report concluded that with 40% RAP content, the black rock exhibited significant differences in laboratory performance compared with the actual practice and total blending mixtures. There were no significant differences between the total blending and actual practice mixtures (McDaniel et al., 2002).

Stephens, et al. (2001) conducted an experimental program to evaluate the effects of blending between RAP and virgin binders on the resulting Superpave grade to validate that RAP does not act as a black rock and has an effect on the overall blend. The difference between the prepared samples was the RAP preheating time before being added to virgin aggregates and binder, if RAP acts as a black rock, preheating time should not have any effect on the mix properties. In contrast, if long heating times facilitate the blending between aged and virgin binders, an increase in the mix strength should be detected. In addition, when comparing the mix with no preheating to the mix made with virgin materials, an increase in strength is immediately observed upon adding the RAP to the virgin materials, even without any preheating. It can be concluded that as RAP is added to mix, the stiffness also would be changed. However, the preheating time and temperature can change the mix stiffness.

In order to simplify the visualization of the blending of the virgin and the reclaimed materials, different particles of virgin aggregate and RAP size mixed with virgin binder were done. Complex modulus and phase angle of reclaimed binder extracted from the mix were measured, and the results show that blending is not homogeneous throughout the sample. Some locations show a good blending whereas other locations appear non-blended with micro-cracks forming at the binder boundaries (Rinaldini et al., 2014).

On the other hand, the amount of RAP content can change the blend degree that involves several physical and chemical phenomena. In order to understand and control the RAP behavior, Bressi et al., (2015) proposed a methodology to detect the existence of a cluster phenomenon (Figure 1) and they also propose a first approach to show a different aging level in the RAP binder film thickness (i.e. partial differential aging). A quantity of new bitumen, which is needed to add, was determined at first step, and then the verification and quantification of the phenomena detected in the first part, were carried out. The cluster formation might have important consequences on the RAP mixture behavior. Clustering could prevent the uniform distribution of the virgin binder, which results in an increase of the heterogeneity of the mixture.

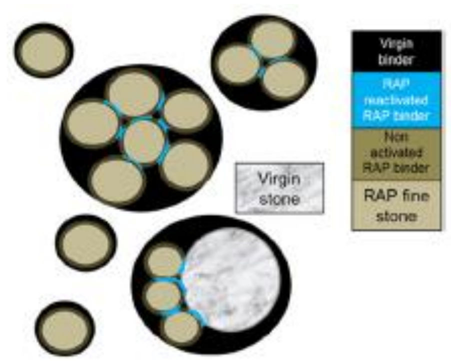

Figure 1: Schematic diagram of cluster phenomenon (Bressi et al., 2015)

Moreover, they indicated that the quality and quantity of virgin aggregates could play a main role in the cluster formation, as well as aggregate shapes and aggregate texture.

In order to insert as much RAP as possible in HMA, a coarser HMA mix has been encouraged by Superpave mix design method which requires tight control of both the overall gradation and percent passing the 0.075-mm (No. 200) screen. Implementation of RAP has been seriously limited because stockpiles of RAP may have widely varying gradations as well as high percentages of minus 0.075-mm material. One possibility for maximizing the use of RAP in Super-pave mixtures was suggested to screen out the finer RAP fractions (Stroup-Gardiner & Wagner, 1999). This would minimize the minus 0.075-mm material and help produce a more uniform coarse RAP gradation.

Both of these factors should permit a higher percentage of RAP to be used and still meet the Super-pave graduation requirements (Stroup-Gardiner & Wagner, 1999).

Each RAP fraction, fine and coarse, has specific characteristics that should be taken into account when RAP is added into a mix. For instance, fine RAP fractions consistently show higher asphalt content, according to the higher surface area per unit weight. Regardless of RAP source, the portion passing the 1.2mm screen consistently has a binder content of 1.0 to 1.5 percent greater than for the coarse RAP. This agrees with previous research by Scholz et al., (1991) which indicated that using fine RAP could be advantageous since it may provide a noticeable savings in the amount of neat asphalt needed while using a lower percentage of RAP materials. However, it was not mentioned if all this extra binder participates in the mix or if it's just glue aggregates together (cluster phenomenon). The most obvious limitation of using this material in Superpave mixtures is the higher percentage of very fine material. The analysis performed on RAP samples reveals a certain degree of variability in RAP binder content and gradation, being higher in the coarse RAP fraction. As a consequence, dividing RAP into several fractions and using higher percentages of fine RAP fraction would results in less variability of bitumen content and gradation. It was summarized that, splitting the RAP stockpiles on the 1.2-mm screen results in two potential benefits: (a) increased uniformity between the RAP sources in the coarser fractions and (b) a reduction in the material passing the 0.075-mm screen. To maximize implementation of RAP, splitting RAP stockpile into fine and coarse fractions were suggested, but it was not clarified at all.

Stephens et al., (2001) also investigated the concept that asphalt films on coarse aggregates would be more prone to blending with virgin aggregates than asphalt film around fine aggregates. Recovered binder from coarse and fine particles was compared to each other using a Dynamic Shear Rheometer (DSR).They concluded that there is no correlation between variation in the binder stiffness and the asphalt coating of coarse or fine aggregates. The main issue in this domain referred to its exposure to heat and air during production, which is a random process and does not relate to whether the aggregate is coarse or fine. Laboratory testing conducted in this study also indicated that the use of RAP substantially affects the binder blend grade.

To sum up previous researches, it can be concluded that the binder film thickness around fine particles are differing from coarse particles and it was not clarified the impact of different RAP aggregate size in the mix also on the other hand, if whole RAP was added it can cause variability in the final results and these variability made it complicated to characterize RAP in mix as black rock or semi blended materials of fully blended. To come up with that new mix designed developed to make clear vision of the impacts of the RAP aggregate size.

3. OBJECTIVE

The main objective of this study is to evaluate the impact of RAP gradation on Hot Mix Asphalt. It is needed to determine how much binder can be transferred during mix from RAP to virgin aggregate.

In this study, a single source of RAP was separated into different sizes and mixed with a specific group of virgin aggregates. Then, according to their size, the mixes were separated again into the RAP group and virgin aggregate. RAP active binder transferred to virgin aggregate while these groups were mixed. Then ignition test (ASTM D6307) was adapted to separate RAP binder from virgin aggregate. As a result of this project, it is possible to figure out activated binder amount in coarse RAP particles and fine RAP particles for a given temperature and mixing time, Finally Indirect Tensile Test was adapted to evaluate the quality of different mixes.

4. MATERIALS

The mobilization of RAP binder defines the RAP binder that transfer from RAP aggregates to virgin stones or mix with the virgin binder. In order to evaluate the mobilization of RAP binder, a single source of RAP and a single source of aggregate are adapted to minimize the impact of different sources of material on the final result. On the other hand, RAP was blended with aggregate without adding virgin binder in order to have a clear vision of RAP binder mobilization.

In this experimental program, a dense graded 20 mm HMA commonly used as a base course in Quebec (GB20) was designed with a PG 64-28 binder. The selected virgin binder (PG 64-28) is a medium grade asphalt binder that can be used in warm climates. Three different classes of virgin aggregates were selected to produce the GB20 blend with the inclusion of RAP without adding virgin binder. The control points for GB-20 pavement mixture are shown in Table 1.

In order to meet the hot mix requirements, the proportions of each aggregate gradation must be determined. The particular aggregates were selected based on LC method specifications such as maximum passing percentage of coarse particles, minimum Passing percentage of coarse particles and the mid-point of specification. In order to achieve desired gradation, mix design was obtained from 5 different classes of aggregates and a source of RAP. The properties of different stockpile are presented in Table 2.

Table 1. The control points for GB-20

	Specification
Sieve mm	GB 20
28	100
20	95-100
14	67-90
10	52-75
5	35-50
2.5	-
1.25	-
0.63	-
0.315	-
0.16	-
0.08	4,0-8,0

Table 2. Different class of aggregates used

	RAP	filler	0-5	5--10	10--14	14--20
Sieves						
28	100%	100%	100%	100%	100.00%	100%
20	100%	100%	100%	100%	100.00%	85%
14	100%	100%	100%	100%	89.45%	13%
10	90%	100%	100%	91%	28.00%	2.6%
5	57%	100%	93%	4%	8.13%	2.0%
2.5	36%	100%	48%	1%	3.73%	1.7%
1.25	23%	100%	28%	1%	1.97%	1.5%
0.63	13%	100%	16%	1%	1.47%	1.40%
0.315	6%	99%	7%	1%	1.33%	1.32%
0.16	2%	93%	4%	1%	1.25%	1.23%
0.08	1%	79%	2.3%	0.40%	1.16%	1.11%
Filler					1.12%	1.09%

5. METHODOLOGY

The methodology of this project can be divided into different steps (Figure 2). First, a GB20 mix design with and without RAP was performed. Then, the mobilized RAP characteristic was quantified with the ignition test, and finally, the mobilized RAP evaluation was done. In this project, fine particles are defined as virgin aggregates, or RAP particles, which pass through the 5mm sieve, and coarse particles were defined as those particles which were retained on the 5mm sieve.

According to LC method specification, sieve analysis should be done to separate coarse from fine particle in RAP and virgin Aggregate. Table 3 indicates different scenarios of blending virgin aggregate and RAP particles according to their size and percentage. There are two parts in each sample, one part RAP and one part virgin aggregate as it was shown in Table 3.

The mix design properties are performed step by step which are mentioned here:

a. Prepare corresponding weighs of fine (820g, 1000g, and 700 g) and coarse (1180g, 1000g, 1300g) from RAP and virgin aggregate.
b. The RAP is heated in an oven at a temperature of 60 ° C ± 5 ° C, stirring frequently. It is not possible to heat the RAP with the aggregates. It is only necessary to heat the aggregate to a temperature of 15 ° C to 25 ° C higher than the heating temperature for mixing specified in LC 26-003test, without exceeding a temperature of 190 °C. The desired binder in this mix is 64-28, so the mix temperature should be 155 °C. Consequently, aggregates preheating temperature are 180 and compaction temperature is 145° C. It should be precise, that the mixing temperature was chosen according to the binder, but that no virgin binder was added.

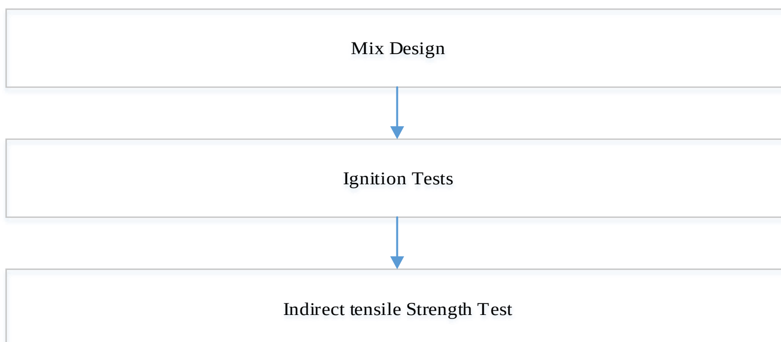

Figure 2: Steps of program

c. In this step preheated RAP was added to the virgin aggregates. The RAP is a separate raw material; it is brought via the mixer, and mixed with preheated virgin aggregate, so that the end temperature is about 155 ºC. This process is referred to in the literature as hot recycling, using Batch plants with a separate heating drum. After mixing, the mix is cool down back to room temperature.
d. Separate coarse from fine again by using the sieve 5 mm for each sample.

Table 3. Different Mixes of virgin aggregates and RAP particles

N	%fine		%coarse	
	RAP	Virgin	RAP	Virgin
FR41CV59	41%			59%
FV41CR59		41%	59%	
FR50CV50	50%			50%
FV50CR50		50%	50%	
FR35CV65	35%			65%
FV35CR65		35%	65%	

The asphalt binder content of the RAP was determined using LC26-006 or ASTM D6307 ignition test methods. The values of indirect tension (IDT) strength was used to evaluate the relative quality of bituminous mixtures in conjunction with laboratory mix design testing and for estimating the potential for cracking. In this study, samples of 150mm in diameter were compacted with a Superpave gyratory compactor, and the indirect strength is calculated with the following equation:

$$S_t = \frac{2000 \times P}{\pi \times t \times D} \quad [1]$$

St = IDT strength, kPa
P = maximum load, N
t = specimen height immediately before test, mm
D = specimen diameter, mm

6. RESULT

The different GB20 designed in this project all have the same gradation. According to specified gradation showed in Figure 3, three different fine RAP percentages were added to coarse virgin aggregate and three coarse RAP percentages was added to fine virgin aggregate. The weight of the samples was measured before and after separation to determine the amount of lost materials during this process. According to the comparison of these two conditions, around 20 % percent of binder was transferred to virgin fine aggregates when coarse RAP was added. Mobilized RAP includes binder and mastic which can be taken from RAP. There are several factors that can change the mobilized RAP content. According to the literature, we are supposed to get more mobilized binder in fine RAP compared to coarse RAP. Mix temperature, time and amount of binder also can help RAP binder coat virgin aggregate properly.
As it can be seen in Figure 3, separated fine and coarse particles were tested in order to figure out the binder content. It was expected that fine RAP has more percentage of binder. Binder content can be increased with the growth of aggregate surface area and make aggregate gradation finer. RAP binder content was determined by ignition test. Ignition oven gave us 5.22% of binder content for the total RAP (fine and coarse part together). Additionally, the binder content was found separately in fine and coarse particles (3.68% Coarse RAP binder content and 6.6% Fine RAP binder content).

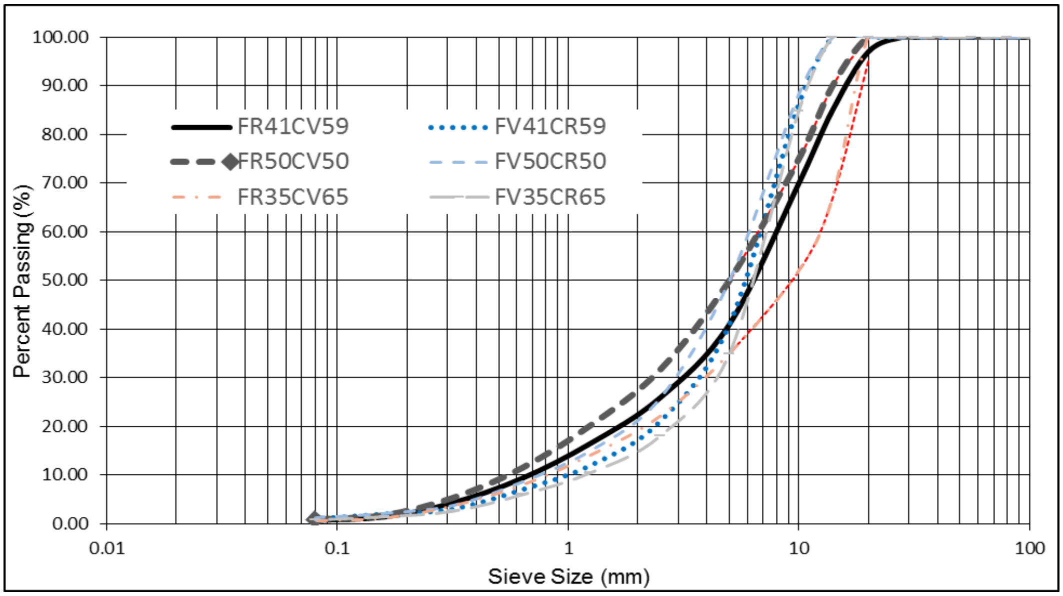

Figure 3: blend aggregate gradation

Because of the higher binder content in fine RAP, it was expected that after mixing, coarse virgin aggregates would have adsorbed or absorbed more binder than the fine virgin aggregates that were mixed with coarse RAP. Samples with Coarse RAP seem more homogeneous than samples with Fine RAP (Figure 4).

Figure 4: Mixture with inclusion of Fine virgin aggregate and fine RAP

Despite the higher binder content in fine RAP, results in Figure 5 show that the binder content in fine virgin aggregate is much more than coarse virgin aggregate.

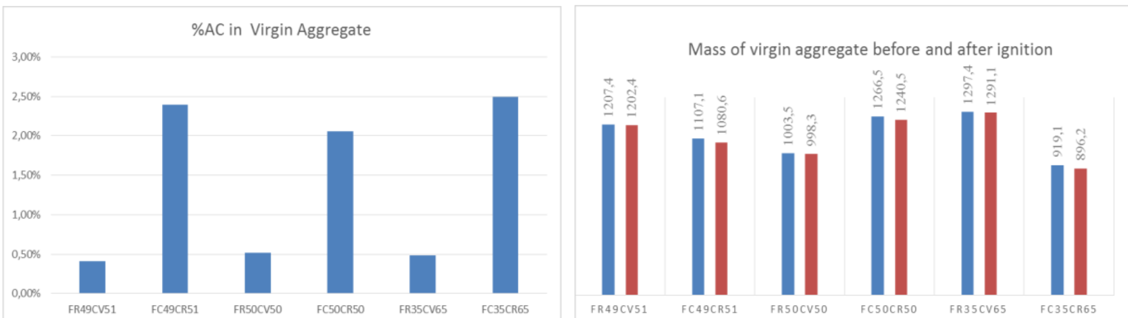

Figure 5: %AC of virgin aggregate by ignition test

This means that more RAP binder transferred from coarse RAP than fine RAP particles. It can be referred to surface area of virgin aggregate. Virgin aggregates have a rough surface. The rough texture can cut off the RAP binder from RAP aggregate during the mix. So, particles which are in contact to the rougher texture could participate more in the mix. Coarse RAP has more chance to face with a rougher texture than the fine RAP.

The surface area can play a main role in this domain. Fine graded aggregate has more surface area than the coarse. As we have different kind of gradations so it was needed to see the surface area factor. The surface area is determined by multiplying the surface area factors (given in the Asphalt Institute Manual) by the percentage passing the various sieve sizes (Clark et al., 2011).

However, they could not find the background research data for the surface area factors in the literature. They concluded that further research is needed to verify these surface factors and the concept of film thickness. Actually the rough surface area or the virgin aggregate surface area was needed. Figure 6 shows the surface area according to samples gradation. Almost the same surface area is reported for each group so it can be concluded that the total surface area can't explain perfectly the transferred binder. So, we need to present the rough surface area. Rough surface area was calculated from virgin aggregate part in each sample. With respect to the Figure 6 and Figure 5 it can be summarized that the rough surface may effect on binder transferring. According to the higher rough surface area, more RAP binder can mobilize from RAP to virgin aggregate.

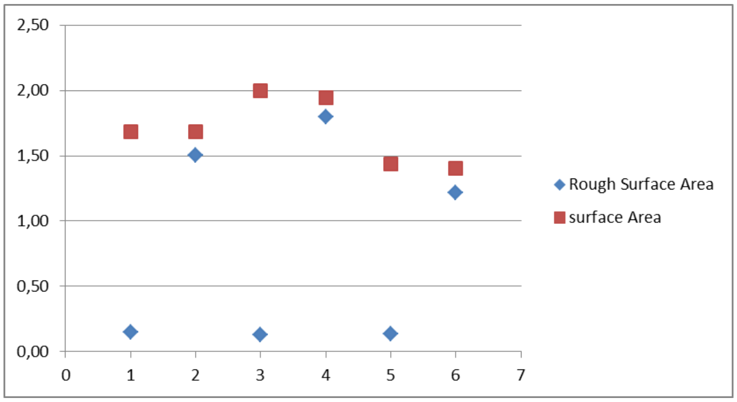

Figure 6: Surface Area

Previously, it was understood that despite the fact that fine RAP has more binder, coarse RAP has more transferred binder according to the high virgin aggregate surface area. We needed to compare the impact of coarse and fine RAP precisely. For that, indirect tension was performed on three different mixes for which the gradation is presented in Figure 7. For those mixes, 34% RAP was added as fine RAP, coarse RAP or complete RAP. In order to have the same overall gradation, the virgin aggregate gradation was adjusted for each mix. As for the first part, no virgin binder was added, but the mixing and compaction temperature was taken as if a PG64-28 binder was used.

As it can be seen in Figure 8, except those mixes with inclusion of fine RAP, all the rest could not hold themselves together after 200 gyrations (not enough cohesion). The main reason was the lack of proper binder content. Fine RAP has enough binder content to hold virgin aggregate without adding virgin binder, but it was doubted that available binder content could change rheological properties of the mix or at least it could be able to cover virgin aggregate, consequently decreases the virgin binder content.

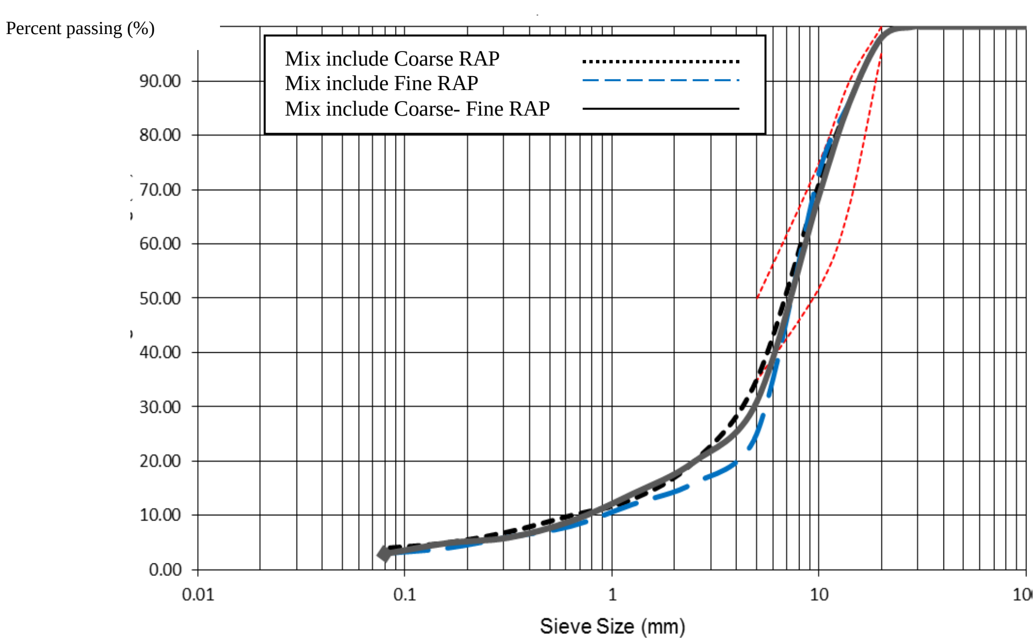

Figure 7: Samples Gradation

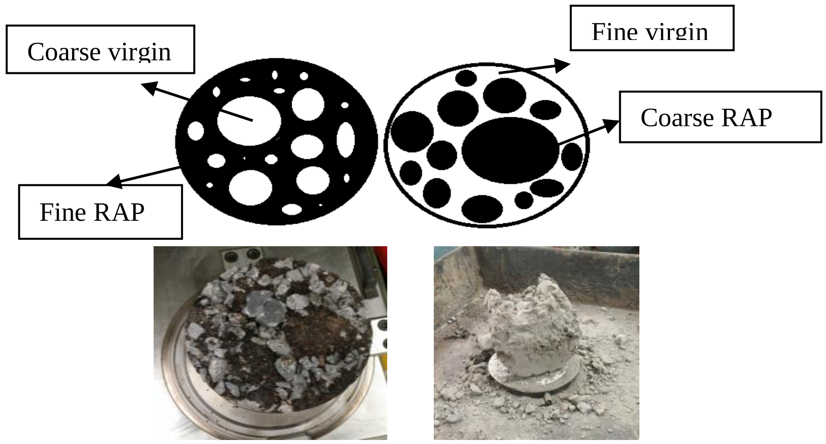

Figure 8: samples cohision after gyratory compaction

7. CONCLUSION

This study investigates the impact of RAP gradation on effective binder in HMA. Binder content in fine RAP particles is higher than in coarse RAP particles because fine particles have more surface area compare with coarse particles. It means that binder content in different RAP particles varies according to its aggregate gradation. Differences in binder content can change the amount of required virgin binder in the mix. On the other hand, it was doubted that if RAP participate in mix as black rock or its binder blends with virgin binder partially or completely. The level of participation has great impact on choosing the binder type and mix stiffness. Various scenarios were developed to understand the interaction of RAP with virgin aggregate.

In the first part of this study, the same quantity of RAP was added to virgin aggregates in all mixes, but as fine RAP or as coarse RAP. On the second step, final gradation was fixed and 34% RAP was added to mix. Ignition test, and compaction of samples to perform IDT was done. The following conclusions were drawn:

- Fine RAP has higher binder content, but the binder does not participate completely in the mix,
- Transferred binder or mastic from fine RAP to coarse virgin would not be a lot, even it cannot cover virgin aggregates.
- Although it cannot cover the virgin aggregate, it can hold virgin aggregates together without adding virgin binder.
- Coarse RAP has lower binder content compare to fine RAP but when mix with virgin aggregates, more binder transfer from the RAP to the virgin aggregates.
- Although Coarse RAP has more transferred binder, but it cannot hold aggregate properly according to lack of binder content.

Further studies are needed to figure out the impact of mix duration and temperature on the amount of transferring binder also it would be needed to validate these results with a different source of materials.

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