Recycling of Reclaimed Asphalt Concrete Using Warm Asphalt Mixture and Cationic Emulsified Asphalt

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ABSTRACT

Warm asphalt mixture (WMA) and reclaimed asphalt pavement (RAP) are the most memorable sustainable materials in world of asphalt concrete pavements . This research aims to study the warm asphalt mixture for different types of filler materials such as ordinary cement and limestone dust. Beside, this research focused on the test of emulsified asphalt properties by evaluating the performance of warm asphalt mixture by Marshall Stability properties as well as moisture sensitivity. The results of this experiment provided many important points. First, The cationic emulsified asphalt is suitable with RAP aggregate for production warm asphalt mixtures .Second, The effective mixing procedure for warm asphalt mixtures consists heating the RAP aggregate at 100 C^o and then mixing with emulsified asphalt. Because of heating of reclaimed asphalt pavement material can improve the dispersion as well as densification significantly. Furthermore, the warm asphalt mixtures containing filler of cement type improved the Moisture sensitivity performance by mean of increasing tensile strength ratio furthermore enhanced Marshall properties .Finally, It was indicated that optimum asphalt content (2.8%) is the best percentage found based on trail mixes ranging from (1.8 to 3.8) %

Key words : warm mix , emulsified asphalt, Marshall stability, indirect tensile strength test.

اعادة تدوير الخرسانة الاسفلتية المستصلحة باستخدام الخلطة الاسفلتية الدافئة والمستحلب الاسفلتي الكاتيونك

المستخلص

خلطة الاسفلت الدافئة وخرسانة الاسفلت المستصلحة هي المواد المستدامة الاكثر تميزا في عالم رصف خرسانة الاسفلت. يهدف هذا البحث الى دراسة خلطة الاسفلت الدافئة باستخدام نوعين مختلفة من مواد المالئة مثل الاسمنت البورتلاندي الاعتيادي وغبار النورة . بجانب هذا البحث ركز على فحص خواص مادة المستحلب الاسفلتي .وتقيم اداء خلطة الاسفلت الدافئ بواسطة خواص فحص ثباتية مارشال.اثبت النتائج العملية العديد من النقاط المهمة .اولاً ان المستحلب الاسفلتي الكاتيونك كان ملائم مع الخرسانة المستصلحة لانتاج الخلطات الاسفلتية الدافئة .ثانيا ان اسلوب الخلط الملائم لإنتاج خلطة الاسفلت الدافئ تنص على تسخين الركام المستصلح عند درجة حرارة 100 درجة مئوية وبعد ذلك يتم اضافة المستحلب الاسفلتي وخلطه معه. ان التسخين خرسانة الاسفلت المستصلحة يمكنها من تحسين التشتت وكذلك التكثيف بشكل فعال.وعلاوة على ذلك ان الخلطات الاسفلت الدافئ التي تحتوي على نوع الاسمنت كمادة مالئة تحسن اداء الخلطات للحساسية الرطوبة المتمثلة بفحوصات ثباتية مارشال المتبقية ونسبة الشد الغير مباشر وكذلك تمتلك مقاومة عالية لشد الغير مباشر. وأخير ومن خلال عمل العديد من الخلطات التجريبية وجد ان افضل نسب لمحتوى الاسفلت المتبقي الاولي للحصول على افضل نتائج والتي تتراوح (1.8,2.3,2.8,3.3,3.8%) وان افضل نسبة مثالية لمحتوى الاسفلت المتبقي الاولي كانت (2.8%).

الكلمات الرئيسية :الخلط الدافئ ،المستحلب الاسفلتي ،فحص ثباتية مارشال ،فحص مقاومة الشد الغير مباشر

1. INTRODUCTION

Sustainability is important approach today in engineering world. Warm mix asphalt (WMA) and reclaimed asphalt pavement (RAP) are the most memorable sustainable materials in asphalt concrete pavements. WMA is not a new concept, however new innovations and increased usage of WMA has been spurred by the increased focus on sustainable infrastructure systems.

The RAP, as mentioned earlier, is a deteriorated bituminous mix that contains aged bitumen and aggregates. Hence, its performance is poorer when compared to the fresh mix. The purpose of the bituminous recycling is to regain the properties of the RAP, such that it tends to perform as good as fresh mix. Thus, the process of bituminous recycling involves mixing of the RAP, fresh bitumen, rejuvenators and new aggregates in suitable proportions **,Aravind & Animesh 2006**.

RAP is the primary recycled product of the aged asphalt concrete pavement and its use leads to reductions in virgin aggregate and asphalt demand. However, significant performance issues can stem from the individual integration of WMA or RAP materials in asphalt concrete. Asphalt concrete producers have begun to evaluate sustainable construction practices by adding recycled materials and utilizing new technologies. Therefore, asphalt concrete sustainability in today's society is most readily met through the use of warm mix asphalt (WMA) and reclaimed asphalt pavement (RAP) **,Angelo, et al., 2008**.

United States asphalt officials began to take notice of these products and took a European WMA tour in 2002. In 2005, the WMA Technical Working Group was created to introduce these technologies to U.S. asphalt producers and develop preliminary specifications for the allowance of WMA **,Prowell, & Hurley, 2007**. Finally, field trials were conducted over the next few years in many states, NCAT published laboratory results for a number of technologies, and the first WMA International Conference was conducted.

The main objective of Warm mix asphalt is to produce mixtures with similar mechanical properties such as Marshall Stability and indirect tensile strength, durability, and performance characteristics as HMA using substantially reduced production temperatures.

2. EXPERIMENTAL PROCEDURE

2.1 Materials Used

The materials used in this research included cationic emulsified asphalt(CSS-1), RAP aggregate, and mineral filler such as ordinary Portland cement, commercially known (Al-mass) and limestone dust (from lime Factory in Kerbala) and the specific gravity for both fillers was (3.14 , 2.73) respectively. The Reclaimed asphalt pavement (RAP) taken and collected from the Baghdad city Kadhimiya road. The specimen of the recycling asphalt pavement was taken using extraction equipment, RAP aggregate extraction and washing to calculate the asphalt content of RAP was (3.8%). The RAP aggregate gradation was verified by the limits recommended by the specification limits for wearing course of the State Corporation for Roads and Bridges in Iraq **SCRB,2003** except the percentage of filler retained on sieve No. 200. So it has been added to the missing quantity of filler which is (5%) by total weight of RAP aggregate and get the aggregate gradation within specified limits of aggregate gradation for Iraqi specification for surface course**.** Where this gradation used is a job mix formula. The RAP gradation is presented in **Fig.1**. **Table 1. and Table2**. listed the physical properties for RAP aggregate and cationic emulsified asphalt , respectively .

2.2 Warm Mix Design of RAP

In fact, the mix design needs to be an important criterion is as follows:

- ❖ The mix design for RAP and filler material mixes was carried out according to the specification limits of the State Corporation for Roads and Bridges in Iraq (SCRB) was taken as a mid-term between upper and lower limits of aggregate gradation for Iraqi specification for wearing course. Where this gradation used as a job mix formula.

Estimation of Initial Residual Asphalt Content (IRAC) and Initial Emulsified Content (IEC). These estimation done by adopting trial mixes and based on asphalt residual content in RAP. Were these mixes tested for gain some variables such as coating test, mixing and compaction temperature and Marshall properties. Five consecutive percentage were adopted for determine Initial Residual Asphalt Content ranging (1.8,2.3,2.8,3.3,3.8) %. These variables used to verify the mixes practice abilities that were characterized by adequate tests of the above variables. To verify these tests, the initial emulsion content should be considered by total weight of mixture as stated by equation below **Asphalt Institute, 1987, Republic of Indonesia, 1990**. :

$$IEC= \left(\frac{P}{X}\right)*100\% \qquad .... (1)$$

Where: P =% Initial Residual asphalt Content by mass of' total mixture for percentages (1.8%, 2.3%, 2.8%, 3.3%, 3.8%), X value was (55.3%). The initial emulsified content (IEC) for emulsified type used was calculated from the above equation and the results found as (3.25%, 4.15%, 5.06%, 5.96%, 6.87%) by mass of' total mixture.

- ❖ Asphalt Coating and mixing procedures of WAR mix: Several trials were carried out in order to determine the most suitable mixing procedure that would provide the best coating. All mixing trials were carried out manually in a metal bowl with the aid of a large spatula. The total recommended mixing time was about (5-10) minutes. The temperature degree of mixing of warm mix was (100) C^o for obtain on best coating degree between ingredients of mixture. And WMA is produced at temperatures 20 to 55 °C lower than typical hot-mix asphalt (HMA)**,Angelo, et al., 2008.**
- ❖ The curing of compacted samples was carried out in two stages:

- Curing of Compacted Samples for Dry Stability Test. This curing procedure consisted of keeping the newly compacted samples for one day in their compaction molds. Some of the samples were subsequently tested for Marshall Stability and the results obtained were referred to as (dry stability values).
- other samples applied in water Conditioning After removed molds. In this procedure of each compacted specimen were immersed in water at $60C^o$ for 24 hr. During immersed, the samples

would rest on a bed of coarse aggregate in water pan . The samples were subsequently to be well dried and tested for Marshall Stability results obtained referred as (wet stability values) **Aksoy, et al.,2005**.

3. DENSITY AND POROSITY CALCULATIONS

To determine these properties, the samples were weighed dry in air and when fully saturated in water. Where these values with other known parameter used to calculate (bulk density, Air Voids, V.M.A., and maximum specific gravity of paving mixture **ASTM D2041, D3203**.

4. MARSHALL PROPERTIES

Five different Initial Residual Asphalt content ratios were chosen, (1.8%-3.8%) by total weight of mixtures, were prepared with increment of 0.5% to determine the optimum initial residual asphalt content for each RAP mixture. And the corresponding percentages of initial emulsified content (IEC) (3.25%, 4.15%, 5.06%, 5.96%, 6.87%) by total weight of mixtures. The fifteen specimens were prepared and tested and the optimum emulsified asphalt is found as a percentage by weight of the mixture. Marshall specimens prepared according to **ASTM D6927,2010.** The compaction effort was 150 blows per face using the Marshall compactor to meet the design criteria of air voids that ranging between (3 to 5)%. The compaction effort was conducted according to SCRB for Heavy traffic (75 Marshall Hammer blows) given results that the mixes containing high air voids which exceed the allowable range of air voids for hot mixture about (3-5%). While compaction effort (150 Marshall Hammer blows). Where the air voids percent was within the allowable range of air voids (3-5%). Followed placed the specimens in a water bath at 60 °C for 30 to 40 min. and tested for Marshall Stability and flow, And this represent dry condition . While, wet condition another set of specimens were immersed in water at 60C^o for 24 h. then tested for Marshall Stability at 60C^o. The Marshall Stability and flow results obtained were referred as wet stability. The ratio of wet to dry condition referred as retained stability is required for mixtures that containing different percentages of initial residual asphalt content a minimum of three samples are required for each percent**, Aksoy, et al.,2005**.

5. CRITERIA DETERMINE OF OPTIMUM INITIAL RESIDUAL ASPHALT CONTENT (OIRC)

The OIRC is determined based on the main parameters namely: dry Stability, Bulk Density, Air voids, Furthermore Flow and V.M.A values must be evaluated with specifications. All parameters shall be plotted in graphical format versus the residual asphalt Content .

Based on **Fig. 2** For bulk density, **Fig. 3** for air voids and **Fig. 5** for stability it can be conducted that the optimum percentage of initial emulsified asphalt content is (5.06%) and Initial Residue asphalt Content is (2.8%).

6. THE INDIRECT TENSILE STRENGTH (ITS) TEST

In the indirect tensile strength test, a cylindrical sample is subjected to compressive loads along two generators which creates tensile stresses perpendicular to and along the diametric plane causing a splitting failure. Testing is carried out **ASTM D4867**. The test is normally carried out were the first subset was tested in a dry condition (soaked in water for 2 hours at 25 ^{o}C).The second subset was tested in wet condition were inundated for 24 hours at 60 C^o followed by 25 C^o for 2 hours in water bath. All specimens are tested to determine their indirect tensile strengths using a Marshall loading frame fitted with 12.5mm wide concave surface loading strips below and above the Marshall sample and the rate of loading is the same as in the Marshall Stability test, i. e. 50.8 mm per minute , and total number of samples are 15 sample for optimum initial residual asphalt content (%) with different types of filler. The ITS value is calculated using the following formula:

$$ITS= \frac{2P}{\pi * t * d} \quad \ldots \quad (2)$$

Where:

ITS = indirect tensile strength (kPa); Pmax = maximum load at failure (N); t= thickness of sample (mm); d= diameter of sample (mm).

The evaluation of moisture induced damage can be made by determining the Tensile Strength Ratio (T.S.R) as follows:

$$T.S.R = \frac{\text{ST of conditioned (wet) specimen}}{\text{ST of unconditioned dry specimen}} \quad \ldots \quad (3)$$

7. RESULTS AND DISCUSSION

The bulk density of warm asphalt mixture obtained at various initial residual asphalt contents as shown in **Fig.2**. It can be seen that as the emulsified asphalt content increases the bulk density also increases until maximum is reached. The maximum value is obtained at 2.8 percent binder content. Possible way to explain the bulk density trend to binder content for warm asphalt mixture follows the same trend observed for hot asphalt mixture, which show increasing with increase the percentage of initial the, also the result is showing of reduction in the volume and increasing in weight of sample and that mean increasing density. And after certain percentage which known an optimum percentage ,the asphalt material which starting to form film with much thickness which leading to reduce the contact distance between aggregate particles and that resulting increase the volume of the sample which means decreasing in sample density ,**Garber& Hoel 2009**.

Fig.3 shows that, as the binder content increases, the air voids decrease rapidly, up to a certain percentage of binder content. The relations between air voids and binder content follows the same trends observed for hot asphalt mixtures. It may be explained by the fact that as more binder is added into the matrix more voids are filled with binder and therefore the percentage of air voids decreases. In general, the range of air voids percent for hot asphalt mixture about (3-5) %. And air voids values of mixtures with cement filler type are slightly lower than the mixtures with limestone dust filler type. The reduction in air voids is due to the cement particles filling up more of the void space available in the mixture due to fineness of cement particles, increasing packing, and therefore reducing porosity. Therefore the hydration process for cement and developed hydration products would be filled the air voids in mixture and that will be reduced.

Fig.4 show that, initially, as the binder content increases, the V.M.A voids decrease rapidly, up to a certain percentage of binder content and then begins to rises with increasing binder content. It may be explained by the fact that as more binder is added into the matrix more voids are filled with binder and therefore the percentage of air voids decreases. But for any further increase in binder overfills the system, destroys the maximum packing and hence the VMA increases .

Fig. 5 Show that the dry Marshall stability increases continuously as the binder content increases up to a certain percentage of binder content and after this point the stability dropping down with increment of binder content. The difference in dry stability within mixtures with regard to added binder content can be principally attributed to the degree of coating, since all the other factors which might influence the dry stability were kept constant, i. e. compaction level, type of binder and aggregate gradation. As the percentage of emulsified asphalt content was increased, the rate of setting of the emulsified was reduced and hence the coating of the aggregates was improved. The slow rate of setting results in a better distribution of binder and a reduction in the number of uncoated aggregates both of which contribute towards better stability. Although an increase in the amount of emulsion content improves the coating of the aggregate and results in better dry stability, an excessive amount of emulsion content will produce a very wet mix which has two distinct disadvantages. These are the prolonged curing time. The wetter mixtures will certainly require longer time for the water to evaporate in order to reach certain content for compaction, and consequently a longer time for the emulsion to break completely. And **Fig. 5** shows that the dry Marshall stability for mixtures with filler of cement type was higher than that of the mixtures with filler limestone dust type. The increase in dry Marshall stability for mixtures with filler of cement type can be attributed to the cement would reacted with water available in emulsion at first hours from mixing of mixture and developed hydration products which would reducing porosity and increasing the bond cement between cement and emulsion (cohesion and adhesion) and increasing the stiffness and rigidity of mixtures. Therefore, consuming water available in emulsified at first hours from mixing of mixture by evaporation and hydration process would accelerated the gain of strength for mixture at age of test , and this does not occur with the mixtures with filler of limestone dust type. Thus the dry Marshall stability for mixtures with cement type of filler is higher than that of mixtures with limestone dust type of filler at age test.

The wet stability continues to increase as the binder content increases until a maximum is reached. The maximum value is obtained at 2.8 percent residue binder content (5.06 percent initial emulsion content) and the wet stability continues to decrease as the binder content increases, and that can be attributed to the effect of moisture on mixture and causing prevented the evaporation water from mixture, delay the curing process and developed strength of mixture at early age. Thus the wet stability continues decrease as the binder content increases after reached a maximum at the optimum asphalt emulsion content as show in **Fig.6**. The variability of the low wet stability values is attributed to the fact that the specimens, the immersion period capillary soaking, absorbed an appreciable amount of water. The absorbed water may have penetrated between the binder film, and the aggregate surface, causing a reduction in the bonding and adhesion between the aggregate particles. According to that it is found that the wet stability for mixtures with filler of cement type is higher than the mixtures with filler of limestone dust type at age test. This is due to the mixtures with cement filler having good bond (cohesion and adhesion) between ingredients of mixture, as compared with mixtures containing limestone dust as filler. Also, and due to hydration process and developed hydration products which fill the pores and hence binding the ingredients of mixture. So that mixtures will be with air voids and water absorption values lower than that for mixtures with limestone dust type of filler. Thus the effects of moisture on mixtures with cement filler lower than the mixtures with limestone dust filler at age test.

Fig.7 Show that the retained stability increases as the binder content increases until a maximum is reached at the last percent of binder. The retained stability for mixtures with filler of cement type is higher than the mixtures with filler of limestone dust type .This can be interpreted to the low difference between dry stability and wet stability, so represented the little moisture effect on mixtures with cement type of filler due to hydration process and developed the products of hydration to fill air voids and reducing water absorption.

The Flow values for warm asphalt mixtures are represented in **Fig.8** it is found that the flow values started to increases with increasing of binder content until reached to maximum value at the higher percentage of binder. Also it can be noted that the flow values for mixtures with filler of cement type is lower than that for mixtures with limestone dust filler. This can be attributed to the high rigidity, stiffness and low air voids of mixtures with cement filler and this improves the flow values in general.

Fig.9 shows that the Dry Indirect Tensile Strength for mixtures with filler of cement type is higher than that for mixtures with filler of limestone dust type. This is due to the high rigidity, stiffness, higher density and low air voids of mixtures containing cement filler.

Fig. 10 show that the Wet Indirect Tensile Strength for mixtures with cement filler is higher than that for mixtures with limestone dust filler. This behavior is attributed to the low air voids of warm asphalt mixture with cement filler leading to low water absorption. Therefore, the moisture effects on mixtures with filler of cement type are lower than that for mixtures with filler of limestone dust type. And that can be attributed to the cement which reacts with water available in emulsion content at first hours from mixing of mixture and developed hydration products which would reduce porosity and increasing the bond cement between cement and emulsion (cohesion and adhesion) and increasing the stiffness and rigidity of mixtures with filler of cement type. As a result of the consuming water that available in emulsion by evaporation and hydration process, the gain strength of mixtures is accelerated. This did not occur for mixtures with filler of limestone dust type.

Fig. 11 shows that the Indirect Tensile Ratio for warm mixtures with filler of cement type was higher than the mixtures with filler of limestone dust type. Consequently, Indirect Tensile Strength for warm asphalt mixture is found to be increased with decreasing air void content in a similar behavior that occurs with the hot asphalt mixture.

8. CONCLUSIONS

1. The cationic emulsified asphalt slow setting low viscosity (Css-1) is very suitable with RAP for production warm asphalt mixtures .

2.From many trial mixes it is found that the best range percentages of initial residual asphalt content to produce adequate results for coating test ,mixing ,compaction , and Marshall stability are ranged from (1.8% to 3.8%). And hence the optimum percentage is (2.8%).

3. The effective mixing procedure for warm asphalt mixtures consists of heating the RAP aggregate at 100 C^o and then mixing with emulsified asphalt .This procedure produces appropriate coating degree for compositions of warm asphalt mixture .

4. The compaction procedure required to obtain air voids within allowable range (3-5) % is about 150 blows for each face Marshall Sample for warm asphalt mixture.

5. The warm asphalt paving mixture is suitable to Iraqi environmental conditions because of reducing of temperatures for mixing and compaction.

6. Results obtained from dry Marshall Stability test indicate that stability is gradually increasing with increases in initial residual asphalt content and after specific percentage it was decreasing. Maximum Marshall Stability obtained for mixtures with cement filler is 13.6kN and 11.2kN for mixtures with limestone dust filler.

7. Generally, it is believed that the warm asphalt mixtures containing filler of cement type having indirect tensile strength higher than that for warm asphalt mixtures containing filler of limestone dust type.

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Table 1 Physical properties of aggregates

Property	ASTM Designation	Test Results	SCRB Specification(2003)
Coarse Aggregate :			
1.Bulk Specific Gravity	C-127	2.63	……
2.Apparent Specific Gravity	C-127	2.65	……
3.Water Absorption,%	C-127	0.41	……
4.Percent Wear by Los Angeles Abrasion ,%	C-131	12	35 Max
Fine Aggregate :			
1.Bulk Specific Gravity	C-128	2.64	……
2.Apparent Specific Gravity	C-128	2.67	……
3.Water Absorption,%	C-128	0.43	……

Table 2. Physical Properties of cationic emulsified asphalt slow setting low viscosity (CSS1).

Test	ASTM Designation (D244)	Test Result	Specification Limits (D2397) for CSS-1	
			Min.	**Max.**
Particle Charge Test	D244	positive	positive	
Viscosity, Saybolt Furol at 25°C	D244	26	20	100
Residue by Distillation, %.	D6997	55.3	57	……
Residue By Evaporation	D6934	54.9	50	70

Sieve Test,%	D6933	0.02	……	0.10
Cement mixing test, %	D6935	0.732	……	2.0
Settlement Test,5day,%	D6930	0.1	0	1
1 Day Storage stability test, %	D6930	0.04	0	1
Tests on Residue				
Penetration, 25°C (77°F), 100 g, 5 s	D5	133	100	250
Ductility, 25°C (77°F), 5 cm/min,	D113	185	40	……
Solubility in trichloroethylene, %	D2042	99	97.5	……
Specific Gravity at 25°C	D70	1.02		

Plate 1. Sample Arrangement for ITS Test Using Marshall Stability Loading Frame.

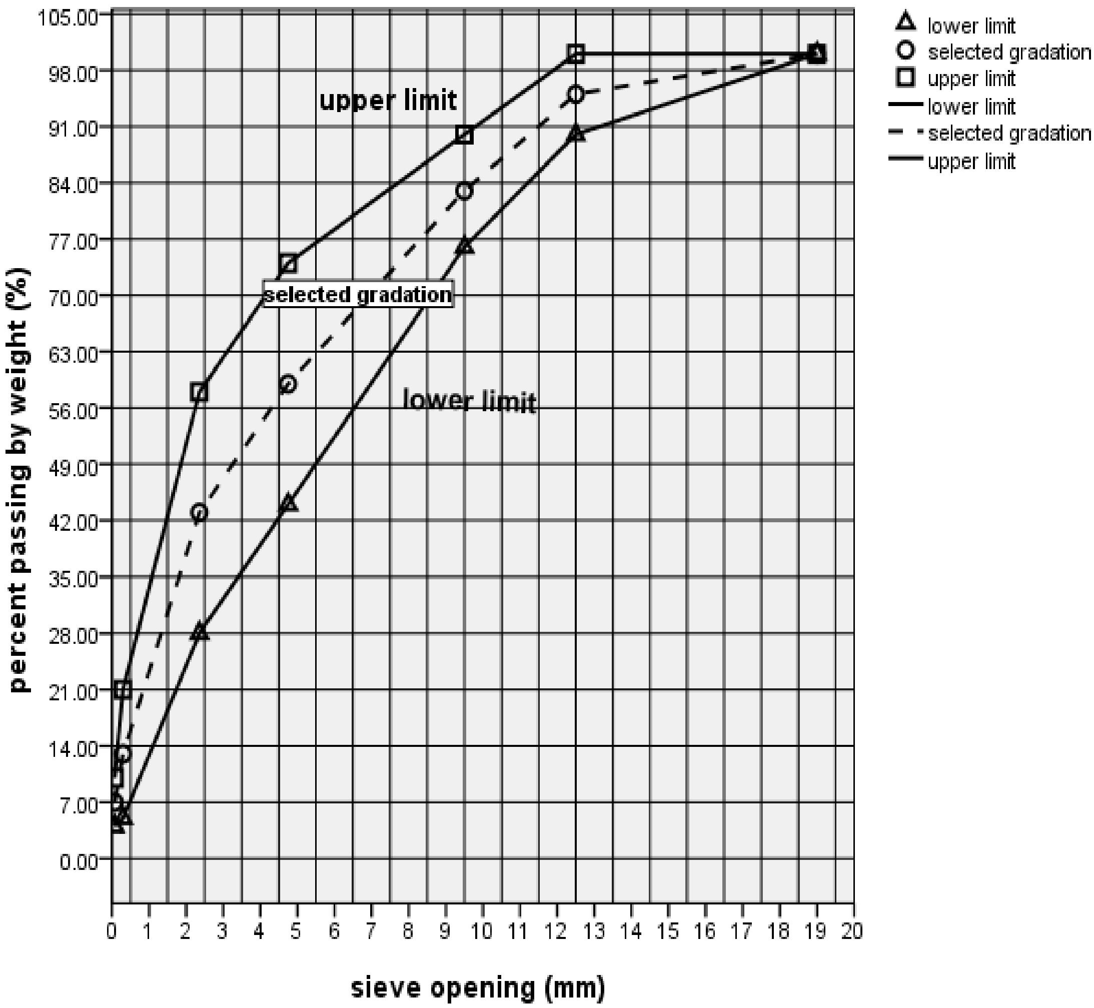

Figure 1. RAP aggregate gradation chart for wearing course.

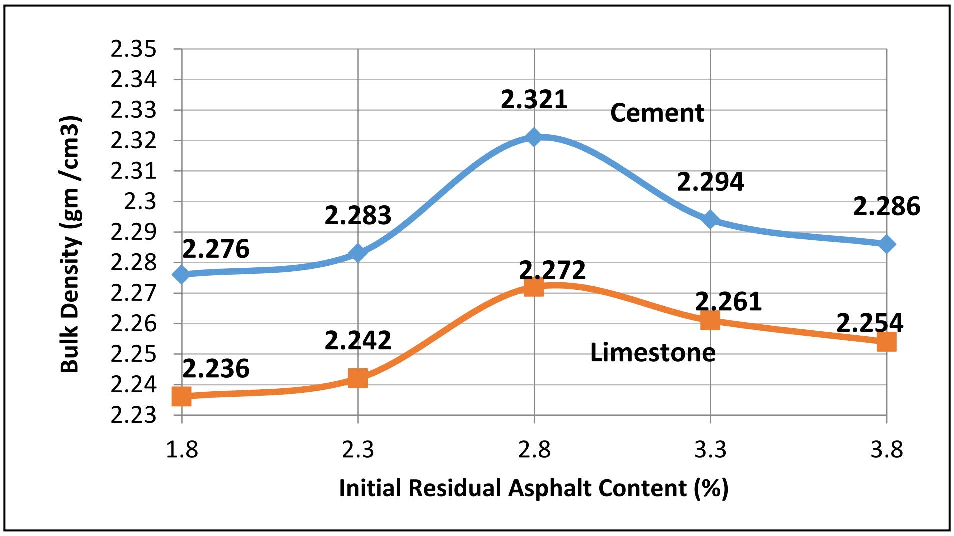

Figure2. Bulk density with initial residual asphalt content (%) for different types of filler.

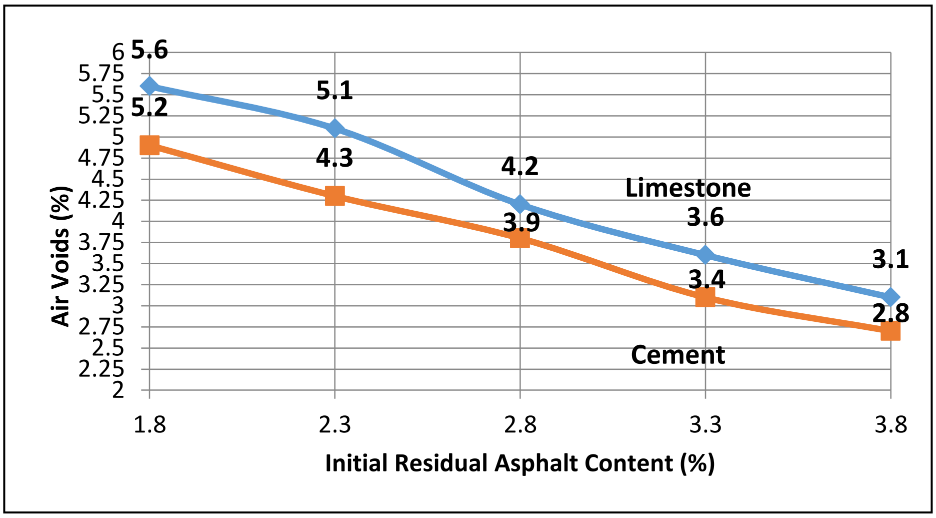

Figure3. Air voids with initial residual asphalt content (%) for different types of filler.

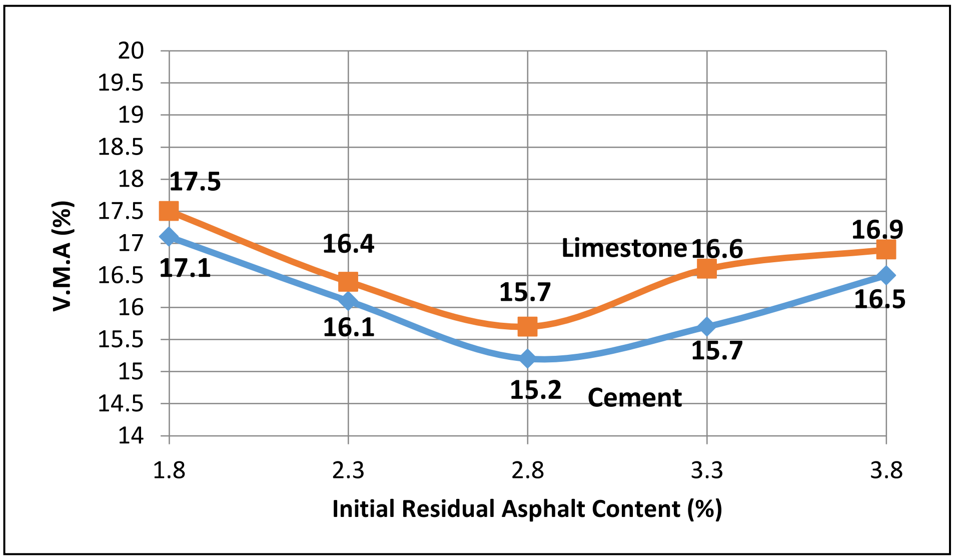

Figure 4. V.M.A% with initial residual asphalt content (%) for different types of filler.

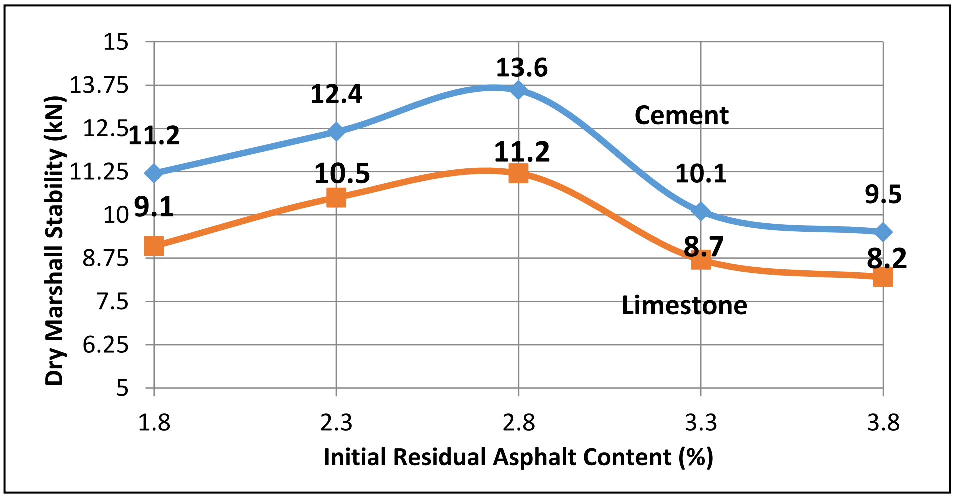

Figure 5. Dry marshall stability with initial residual asphalt content (%) for different types of filler.

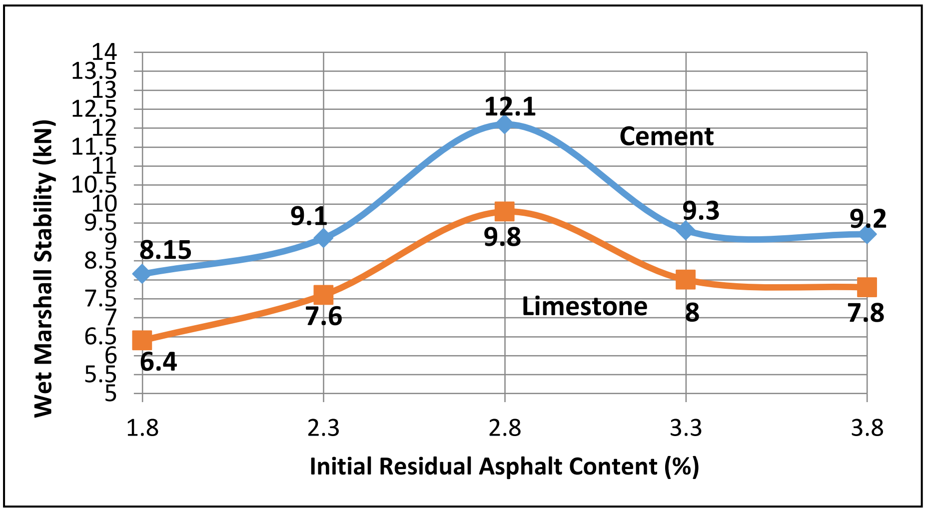

Figure 6. Wet Marshall stability with initial residual asphalt content (%) for different types of filler.

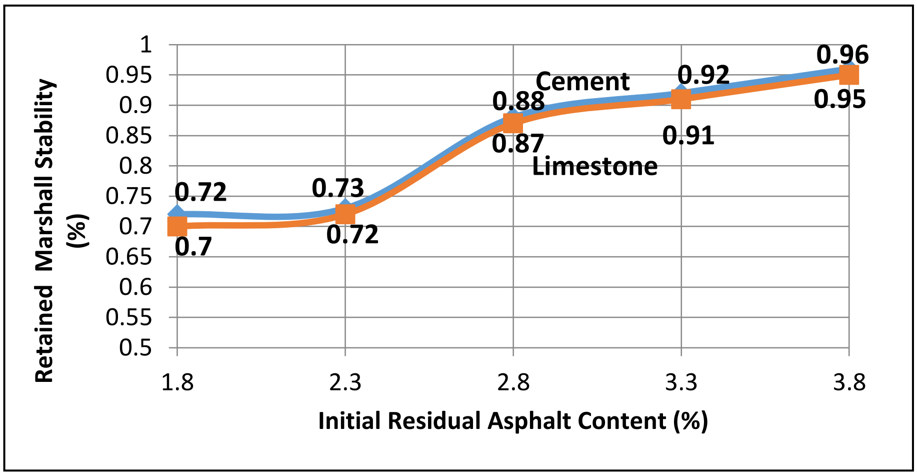

Figure 7. Retained Marshall Stability with initial residual asphalt content (%) for different types of filler.

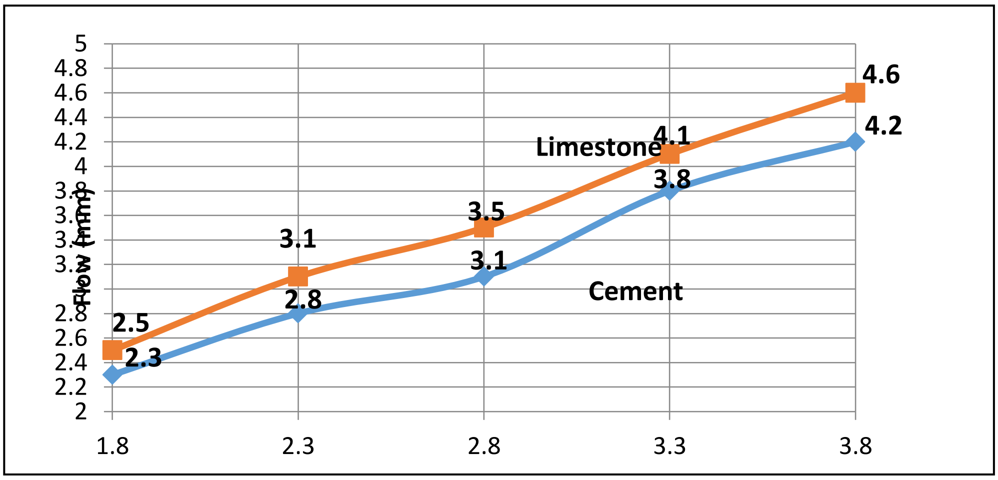

Figure 8. Flow value with initial residual asphalt content (%) for different types of filler.

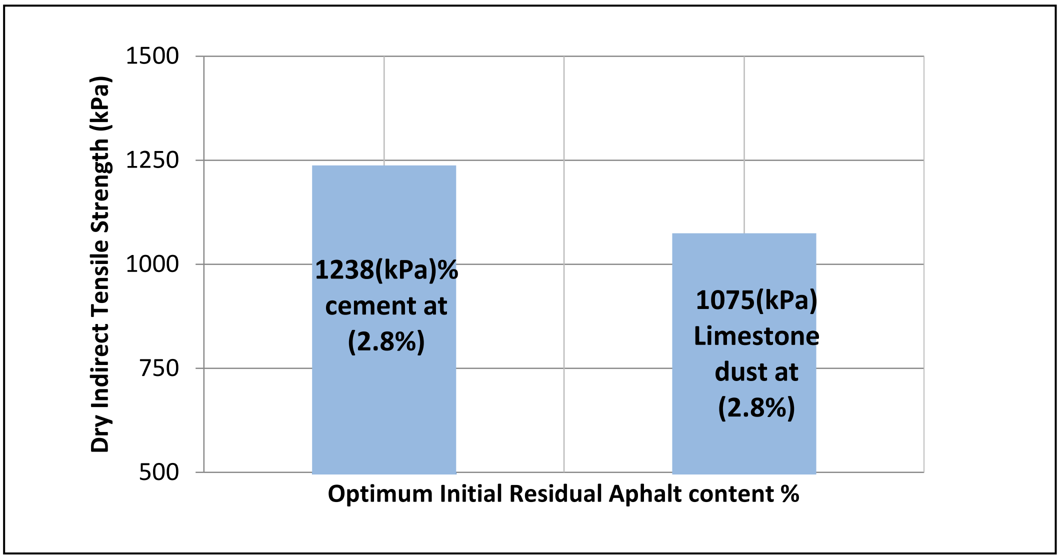

Figure 9. Dry indirect tensile strength (kPa) with initial residual asphalt content (%) for different types of filler.

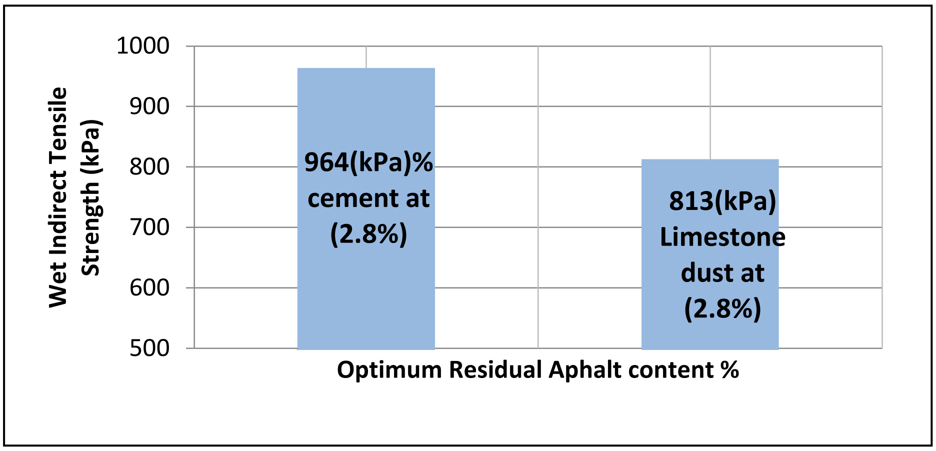

Figure 10. Wet indirect tensile strength (kPa) with initial residual asphalt content (%) for different types of filler.

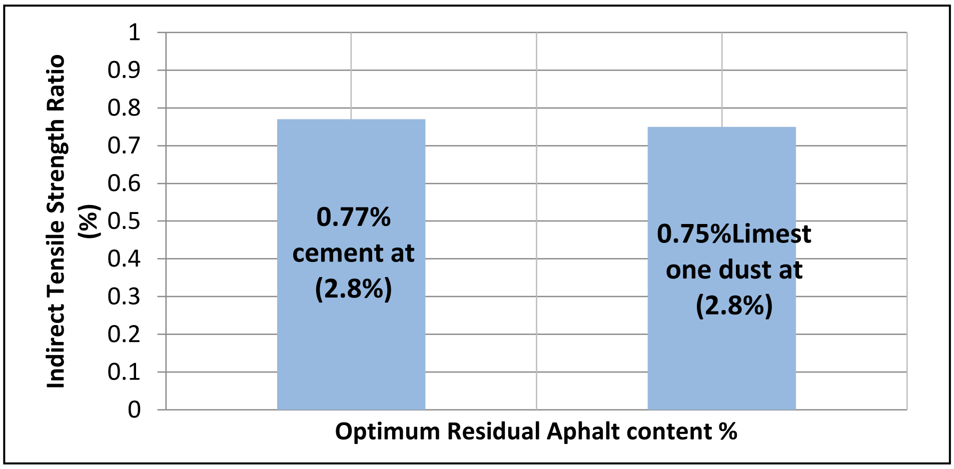

Figure 11. Indirect tensile strength ratio with initial residual asphalt content (%) for different types of filler.