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Evaluation of Aggregate Gradation Effect on Rutting Performance of Hot Mix Asphalt (HMA) using traditional and Bailey methods

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ملخص البحث:

إن العديد من الجهات المسئولة عن رصف الطرق تستخدم طرقاً مختلفة لتصميم الخلطات الأسفلتية الساخنة (HMA) مثل (Marshall, Super Pave, Hveem) وكل هذه الجهات تعتقد أنه يجب عمل تغييرات أساسية في تدرج الأحجار المكونة لهذه الخلطات للحد من التخذد إلى المستوى المسموح به. إن خصائص الخلطات الأسفلتية الساخنة مثل الثبات, والإنسياب, والمقاومة للعوامل الجوية, ومقاومة التخذد تتأثر بصورة كبيرة بفعل تدرج الأحجار المكونة لها ومن هنا فإن خاصية تدرج الركام تعتبرمن الخواص الأساسية المؤثرة في أداء الرصف الأسفلتي . وعموماً هناك عوامل أخرى مثل الدمك, والمحتوى الأسفلتي, والخصائص الفيزيوكيميائية للأسفلت المستخدم, وشكل ونوع ومصدروصلابة الحبيبات وغيرها لها أيضا تأثير على أداء الرصف .

إن طريقة مارشال في تصميم الرصف تتضمن اختيار تدرج الركام المناسب ودرجة الدمك المناسبة بطريقة المحاولة والخطأ ثم يخلط هذا التدرج بنسب مختلفة من الأسفلت ويدمك عند مستوى معين ودرجة حرارة معينة. وفي طريقة السوبربيف لتصميم الرصف ؛فإن الخصائص الحجمية للخلطة تدار أيضاً بإسلوب عملية المحاولة والخطأ لخلط مزيج الركام وذلك للوصول إلى خلطة ذات خصائص مقبولة عند درجة الدمك التصميمية. ؛لذلك من الضروري تقييم تأثير تدرج الركام على أداء التخذد للخلطات الأسفلتية الساخنة والأكثرأهمية هو الوصول إلى أداة لتطوير طريقة تصميم مزيج الركام لتحقق كل المعايير الحجمية وأيضاً تكون سهلة التطبيق العملي وتعطي أداءً متميزاً ؛ لهذا فالهدف الأول من هذه الدراسة هو تقييم تأثير تدرج الركام في أداء التخذد للخلطات الأسفلتية الساخنة وتقييم مدى إمكانية تطبيق طريقة بيلي (Bailey Method) على المواد المستخدمة لرصف الطرق في مصر وأيضاً من أهداف البحث تقييم كلا من ثبات مارشال, والإنسياب, ومعامل الصلابة, ونسبة الفراغات الهوائية في المواد الصلبة في توقع أداء الرصف لمقاومة التخذّد.

أيضاً من أهداف هدا البحث التحقق من امكانية استخدام نسب بيلي (Bailey Ratios) في توقع أداء الرصف لمقاومة التخذد لكل الخلطات الأسفلتية سواء المصمم تدرج أحجارها بالطريقة التقليدية (المحاولة والخطأ), أو بطريقة بيلي.

ولتحقيق هذه الأهداف تم استخدام نوعين من الخلطات الأول تم تسميته خلطة الدولوميت (DOL-mix)حيث يتكون من حجمين من ركام الدولوميت الخشن (CA1,CA2) وركام ناعم (رمل طبيعي)(FA) وبودرة (MF). والخلطة الثانية تسمى خلطة اللايمستون تتكون من ركام اللايمستون (CA1,CA2) وركام ناعم (رمل طبيعي)(FA) وبودرة (MF), ثم استخدمت أنواعاً مختلفة من الترجات خشنة وناعمة ومفتوحة وكان مجموع هذه التدرجات 12 تدرجاً , منها 10 تدرجات مصممة بالطريقة التقليدية و2 تدرج بطريقة بيلي .وقد استخدم نوعاً واحداً من البتيومين في كل الخلطات هو (PG 60/70) وقد صممت جميع الخلطات الأسفلتية بطريقة مارشال .

بعد ذلك تم قياس التخذد باستخدام اختبار (WTT) ثم جمعت النتائج وتمت مقارنتها ببعضها وتحليلها ومقارنتها ببعض النتائج السابقة في هذا المجال واستنباط الخلاصة والتوصيات منها .

ABSTRACT:

Many road pavement agencies have been using different methods for designing Hot-mix asphalt mixtures "Marshall , Super Pave , Hveem ,……,etc" and they are believing that fundamental changes must be made in the aggregate components of HMA to reduce rutting to tolerable levels. Properties of HMA such as stability, durability, and resistance to permanent deformation (rutting) can be largely affected by aggregate gradation. Hence, gradation is considered as one of the main properties of aggregate that influences the performance of asphalt pavement. However, other factors such as compaction efforts, bitumen content, and physico-chemical properties of asphalt cement have also some effects on pavement performance. The Marshall Mix design method involves selecting a trial aggregate gradations and Compaction level (number of blows). The trial aggregates gradation is mixed with varying percentages of asphalt cement and then compacted at specific temperature level fixed by viscosity. In Super pave mix design procedures, the volumetric mix design is conducted using trial and error aggregates blending process to find a mixture with the appropriate properties at the design compacting effort. So, it is necessary to evaluate the effect of aggregates gradation on the performance of HMA especially, permanent deformation and the most important necessary tool to develop method for designing asphalt mixtures that utilize aggregates interlock and aggregates packing to develop mixture that meets all volumetric criteria, and which is easy to construct and gives excellent performance. The primary objective of this research is to evaluate the effect of aggregates gradation on rutting performance of different asphalt concrete, and to evaluate the applicability of the “Bailey Method” in Egypt. Also results of stability, flow, stiffness index, and VMA were analyzed and correlated to permanent deformation (rutting) of the investigated mixtures. Using Bailey Ratios of all different blends "Bailey aggregate blends and Traditional blends" have been investigated to predict permanent deformation (rutting) for all specimens. To fulfill these objectives two types of aggregate blends were prepared. The first is named dolomite blends (DOL) were consisted of dolomite coarse aggregates, fine aggregate "natural sand" and mineral filler .The second is named limestone blend (LIM), were consisted of limestone coarse aggregates, fine aggregate "natural sand" and mineral filler. Different gradation types were used in this research included coarse, open and dense gradations. The total were twelve gradations, six gradations for DOL, and six for LIM, were blended using two methods, ten of these gradations were designed by traditional method "Trial and Error" and the remaining were designed by Bailey method. Only one type of asphalt cement, penetration with 60/70, was used in all mixes. Marshall Method was utilized to design the mixtures, and Wheel Tracking Test "WTT" was carried out to evaluate the rutting performance. The comparison between the obtained results was done, and then the conclusions and recommendations were drawn based on them.

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1.Introduction

In practice, Hot Mix Asphalt "HMA" is very simple, but actually is much more complicated than it appears. HMA is a composite material consists of aggregate particles having different sizes (coarse and fine aggregates), an asphalt binder which is a semi-solid viscoelastic material and air voids. In Egypt, “Marshall Method” is used to design and evaluate the HMA. Some countries in the Middle East may use “Super Pave”; although Marshall and Super pave have detailed procedures to determine the asphalt content (AC) of the hot mix, very few instructions are given on how to design the aggregates blend. Super Pave only gives a list of the criteria for aggregates blend in the form of control points "upper and lower limits of percentage passing for certain sieve sizes and restricted zone" a range of values of percentage passing to be avoided for several fine sieve sizes". However, “Super pave and Marshall” don't give any certain definite method to select the aggregates gradation of mix if the criteria are not met. The text only tells the Engineers to go through the process of trial and error.**[11],[12]**

Additional combinations of the aggregates could be tested or additional materials from different sources could be obtained and included in the trial blend analysis. Traditionally, engineers have relied on experience either themselves or from others to design the aggregates blend of mix. Gradation of the aggregates is the most effective property of it, and some properties of HMA such as stiffness, stability, durability, fatigue resistance and resistance to permanent deformation can be largely affected by aggregates gradation. Therefore; gradation is considered as one of the most important properties of aggregates that influence the performance of asphalt pavements, especially permanent deformation. So, in this research, the effect of this property "Gradation of aggregates" on rutting performance was evaluated using different gradations of the same materials. Recently, the engineers have used different methods which provide simplified explanation of mechanics of aggregates structure, the procedure of the aggregates blend evaluation and design, one of these methods is called "Bailey Method". It was initially developed by Mr. Robert Bailey, it is a gradation selection procedure that considers packing characteristics of aggregates. “Bailey Method” is a tool to design the aggregates interlock and aggregates structure in HMA. So, Bailey Method, along with experience, can guide the direction of the mix designs helping to quickly reach a final design that performs well under actual road conditions. **[12].**

Among the range of tests that can be carried out to evaluate the performance of HMA, Wheel Tracking Test "WTT" was used. It is carried out by using scaled traffic loading to directly evaluate the performance of HMA.

2. Rutting:

Rutting of asphalt concrete pavement is the permanent deformation of any of the layers in the structural system. It is considered as one of the most common and destructive pavement distresses as a result of the repetitive traffic loads. Deformation can be caused by consolidation or plastic flow in the pavement layers. One of the contributors to rutting in hot mix asphalt (HMA) pavements is excessive asphalt content which lead to the loss of interlock between aggregate so that traffic loads will be resisted only by asphalt not by the whole mix. Increasing the design asphalt content will decrease the shear resistance of mixtures to induce later movement of materials. An increase in the viscosity of the asphalt cement at the same pavement temperature can improve rutting resistance. For aggregate with larger nominal maximum size, more fractured faces, and more rough surface texture will have obvious effects on mixture to restrain plastic flow.**[8]**

2.1 Rutting Evaluation Tests:

Many techniques have been used in rutting evaluation such as Hamburg Wheel-Tracking, Wheel Tracking Machine, Asphalt Pavement Analyzer, Three-Wheel Immersion Tracking Machine and Third Scale Mobile Model Load Simulator (MMLS3). **[1]**

3. The Bailey Method

3.1 Why Bailey?

After decades of use, a lot of valuable experience with the Marshall mix design method have been obtained. Accordingly there is a degree of comfort in working with the Marshall method in designing mixes. While there has been some guidance on the use of coarse and fine superpave mixes. However, designers are still struggling with mix designs and have to conduct numerous trials to select the proper aggregate blend. A better way to speed up the process and understand the mixes that are being produced is needed.

The Bailey Method is used to create a strong aggregate skeleton by developing the proper voids in the mineral aggregate to achieve good durability and rut resistance. The strong skeleton is created by enhancing aggregate interlock and aggregate structure. The method develops aggregate interlock as the primary support of the structure and a balanced gradation to complete the mixture. Desirable qualities in asphalt are achieved by understanding the packing characteristics of the aggregate through the Bailey Method. The method is directly based on the voids in the mineral aggregate (VMA), air voids, and the properties of compaction**. [12]**

3.2 Aggregate blending

The Bailey method provides a good starting point for mix design and an invaluable aid when making adjustments at the plant to improve air voids, VMA and overall workability of the mix, whether you are using Marshall or Super Pave are used. The bailey method provides this needed assistance to the designer to provide resistance to rutting and long durability or long term performance with the available aggregates. Congruently, the mix must be fairly simple to produce and workable in the field to facilitate achieving good density. The focus in the Bailey method is aggregate packing. In order to understand aggregate packing, what particles form the coarse aggregate structure and which ones fit into the voids created within that structure are needed. The packing characteristics are determined by several factors: the shape, strength and texture of the aggregates, the combined blend gradation, and the type and amount of compactive effort (e.g. Marshall vs. gyratory compaction).

Ultimately, the Bailey method allows the designer to select an aggregate skeleton that will be more resistant to permanent deformation and adjust the VMA by changing the packing of the coarse and fine aggregates to ensure that the mix has sufficient asphalt binder. **[11]**

3.3 The Bailey Method Principles

There are four key principles to be considered with the Bailey Method:

1. Determine what is coarse and fine, what creates voids and what fills them, and which one is in control of the aggregate structure (i.e., the coarse aggregate or the fine?).
2. The packing of the coarse fraction influences the packing of the fine fraction.
3. The fine aggregate coarse fraction relates to the packing of the overall fine fraction in the combined blend.
4. The fine aggregate fine fraction relates to the packing of the fine portion of the gradation in the blend.

3.4 Developing the Combined Aggregate Blend:

After gathering the typical information for the individual aggregates (gradation, specific gravity, etc.) and performing the unit weight tests, a combined blend can be developed and evaluated with respect to the four main principles of the Bailey Method, prior or actually blending the mix in the laboratory. The following steps outline the general procedures for developing and evaluating a trail blend:

Step 1**:** Determine the Mix Type and NMPS
Step 2: Chose the volume of coarse aggregate (i.e., CA chosen unit weight)
Step 3: Blend the individual coarse aggregates by volume
Step 4: Blend the Individual Fine aggregates by volume
Step 5: Chose the desired percentage of minus 0.075mm (#200) in the Combined Blend. **[12]**

4. Research Plan

Two types of coarse aggregates that are commonly used in Egypt which are dolomite and limestone aggregate, from each type two sizes have been selected. The first one is course aggregate (CA2) larger than 9.5mm and smaller than 25mm, while the second is course aggregate (CA1) larger than 2mm and smaller than 9.5mm.

Two additional materials to enhance the performance of the mix, the first one is fine aggregate (FA) which is natural sand passes through sieve (9.6mm, 3/8"), and mostly passes through sieve No. 4 (4.75mm). The second is Mineral filler (MF) passes through sieve (No. 30) and at least 70% passes through sieve (No 200). (0.075 mm.).

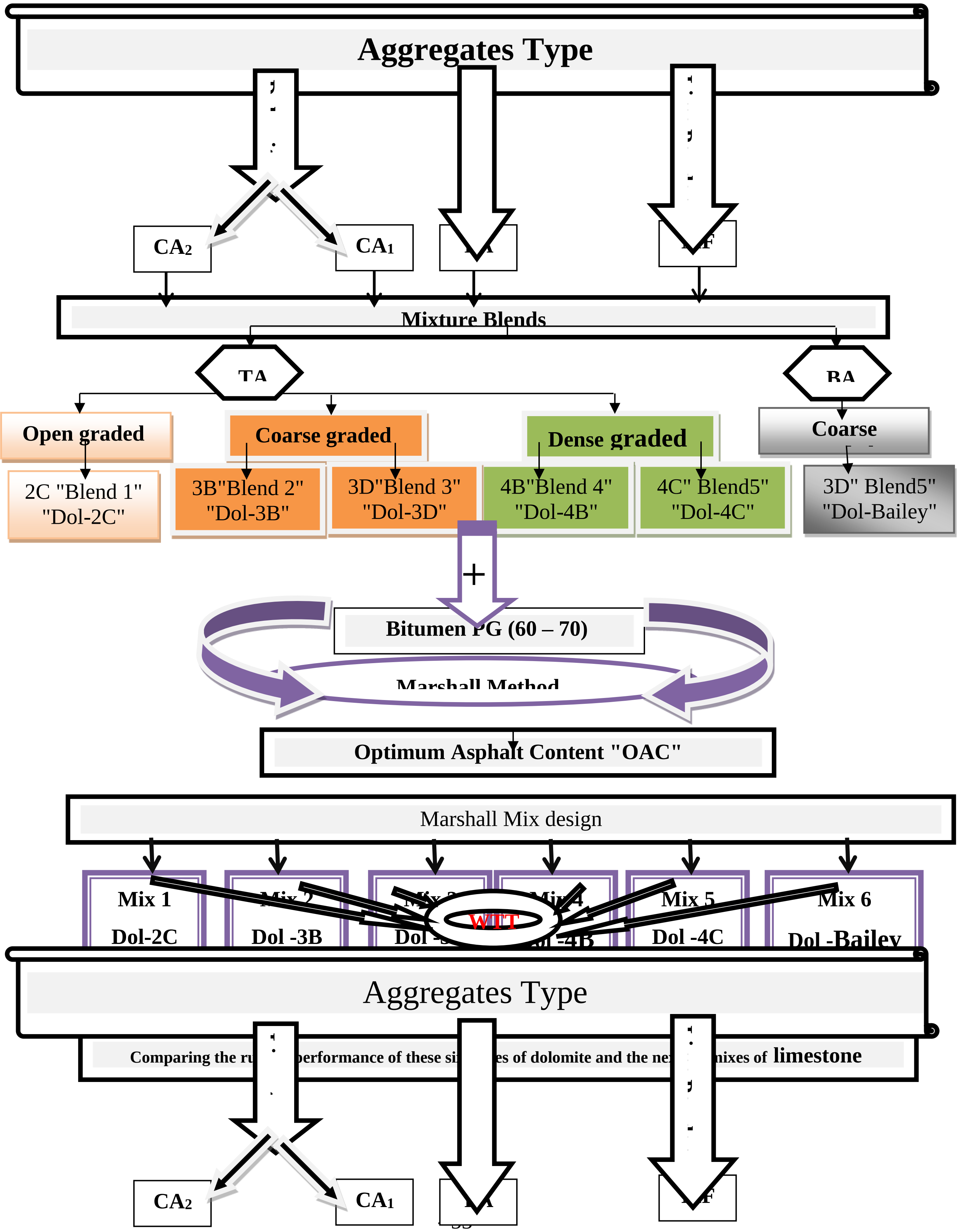
4.1 Aggregates blending and the Optimum Asphalt Content

The dry mix aggregates were blended using two different methods, the first method is trial and error (Traditional Gradation Method "TGM"), while the second is the Bailey method (Bailey Gradation Method "BGM"). In TGM five graded mixes which are (2C"open graded", 3B, 3D"coarse graded", 4B and 4C"dense graded") were prepared using dolomite aggregates and limestone. In the Bailey method one graded mix which is (coarse graded mix) was prepared using dolomite aggregates and limestone, then, they were compared with 3D gradation. All (12) mixes were selected to meet the Egyptian standard specifications. The OAC for all mixes were determined using Marshall and using bitumen (PG 60/70).

4.2 Performance test

To evaluate the performance of all mixes, Wheel Tracking test were conducted on the HMA and the engineering properties were determined and presented.

Figures (1) and (2) show those steps are performed in this study.


Aggregates Type
CA2
CA1
Mixture Blends
TA
RA
Open graded
Coarse graded
Dense graded
Coarse
2C "Blend 1" "Dol-2C"
3B"Blend 2" "Dol-3B"
3D"Blend 3" "Dol-3D"
4B"Blend 4" "Dol-4B"
4C" Blend5" "Dol-4C"
3D" Blend5" "Dol-Bailey"
+
Bitumen PG (60 – 70)
Optimum Asphalt Content "OAC"
Marshall Mix design
Mix 1 Dol-2C
Dol -3B
Mix 5 Dol -4C
Mix 6 Dol -Bailey
WTT
Aggregates Type
Comparing the performance of these mixes of dolomite and the mixes of limestone
CA2
CA1

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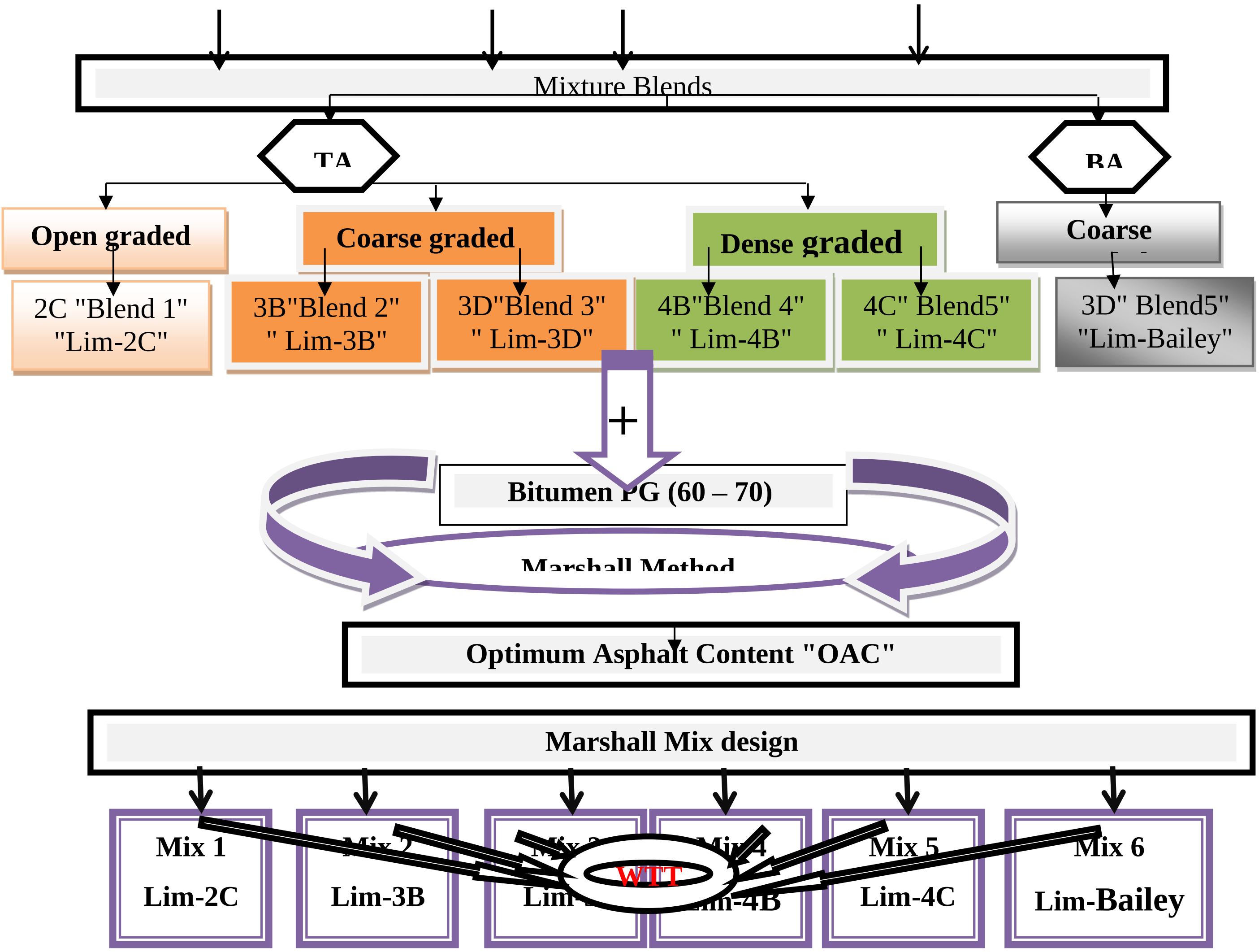

5. Res

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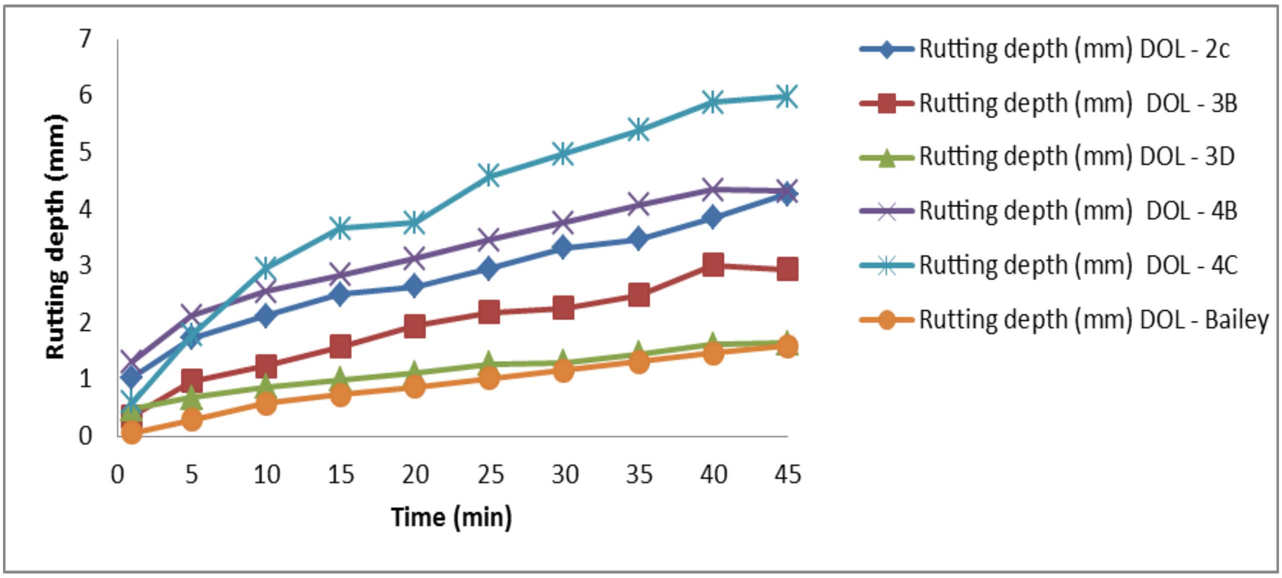
Figure (1-2): Schematic diagram of the experimental program for LIM-MIX.

Comparing the rutting performance of these six mixes of dolomite and the next six mixes of **dolomite**

machine for rutting evaluation. Figures (3) and (4) show the WTT results.



Figure(3)Relationship between time (min) and max. rut depth(mm)for the six DOL-mixes

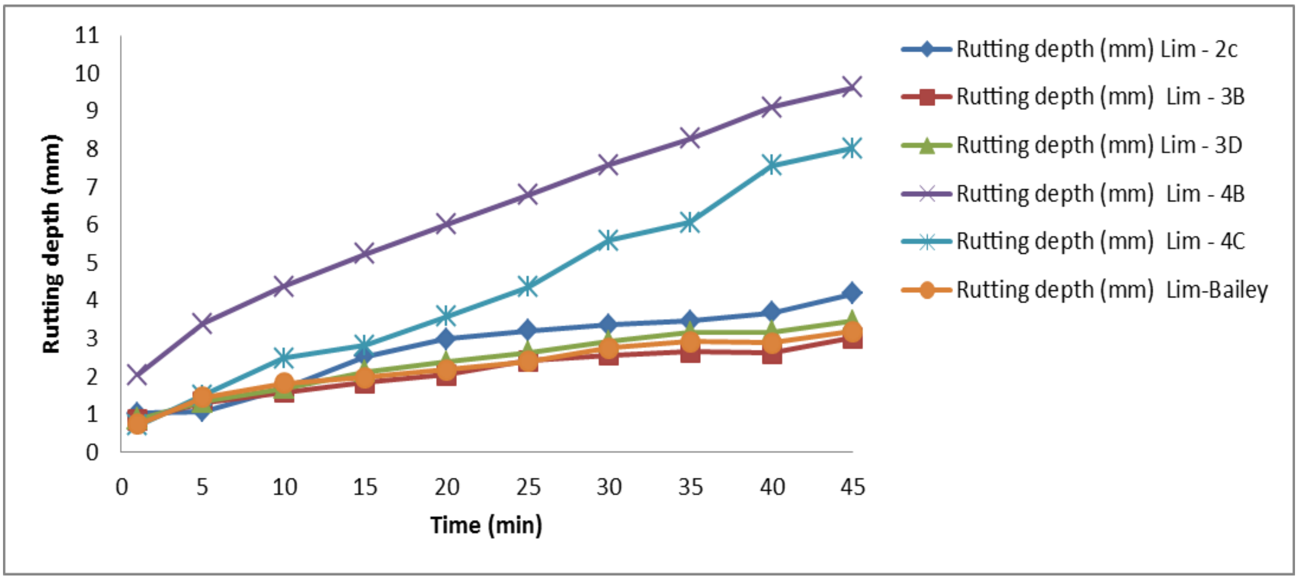
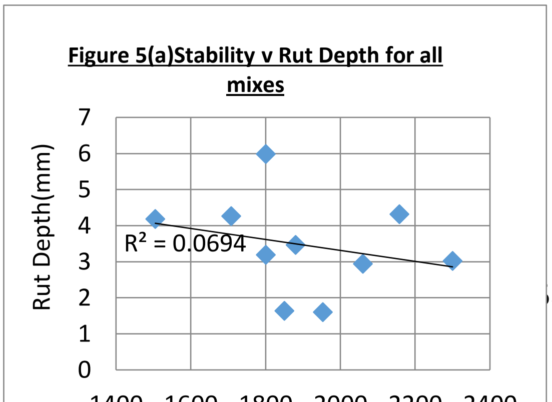
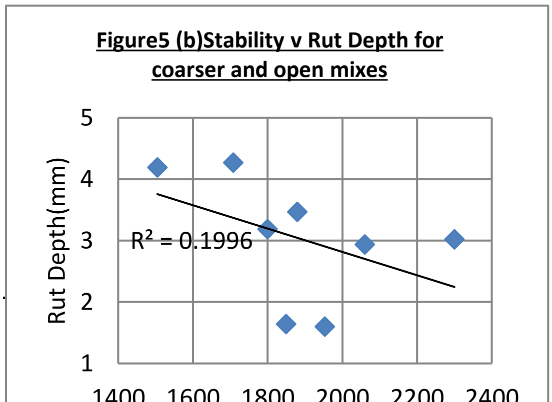


Figure (4) Relationship between time (min) and max rut depth (mm) for the six LIM-mixes

Finally, stability, flow, stiffness, VMA and rut depth values for each mix at OAC were collected. The obtained relationships between rut depth and these parameters that are related to pavement performance (Stability, Flow, Stiffness, and VMA) are drawn in Figures (5) to (8).





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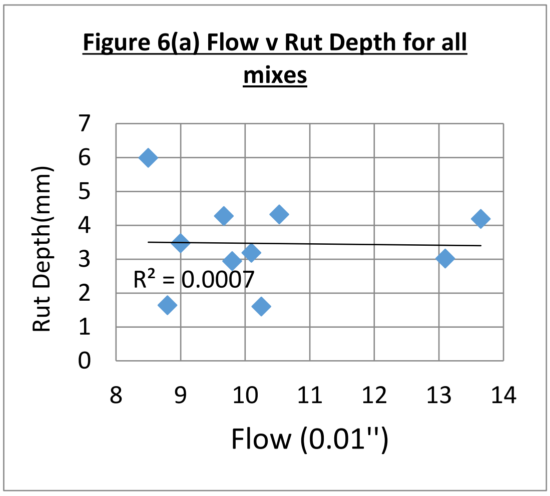


Figure 6(a) Flow v Rut Depth for all mixes

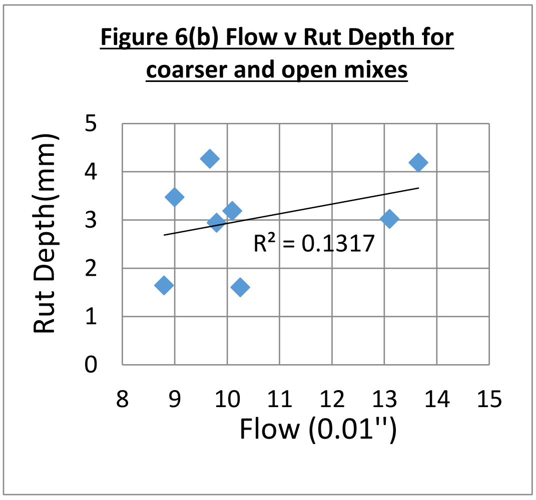
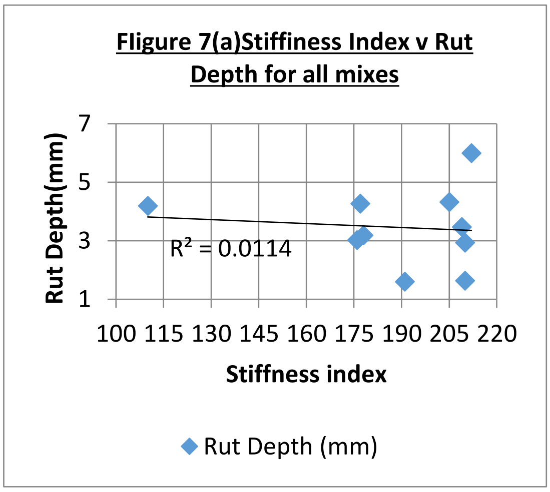


Figure 6(b) Flow v Rut Depth for coarser and open mixes



Fligure 7(a)Stiffiness Index v Rut Depth for all mixes

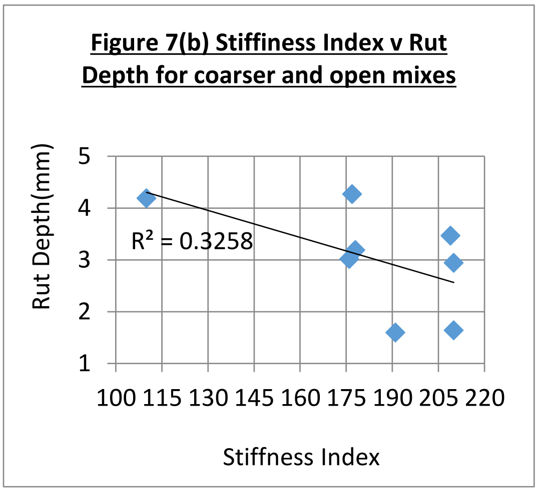


Figure 7(b) Stiffiness Index v Rut Depth for coarser and open mixes

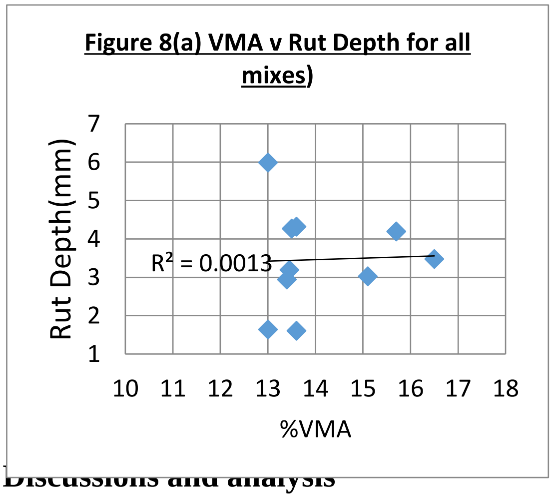


Figure 8(a) VMA v Rut Depth for all mixes)

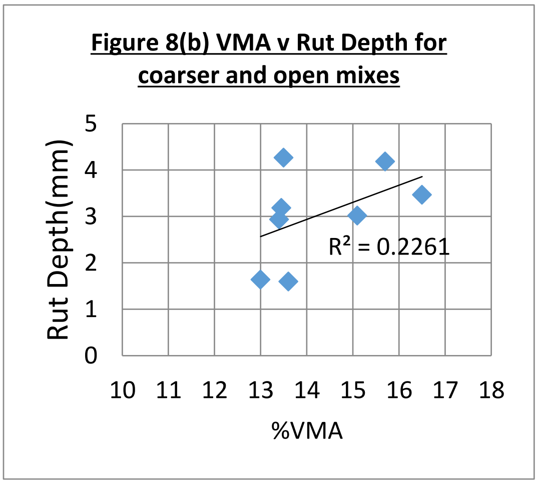


Figure 8(b) VMA v Rut Depth for coarser and open mixes

5. Discussions and analysis

The results from the performance test (WTT) to evaluate rutting performance on the six dolomite mixtures were compared to the six limestone mixtures. Dolomite mixtures with high hardness and lower water absorption aggregate blends were generally showed less rutting .On the other hand, the comparison between the six dolomite mixtures showed generally superior performance in the coarse graded mixes, less performance in the open graded mixes and inferior performance in the dense graded mixes .The best performance of all mixes was DOL-Bailey mix, where the max rut depth value was 1.6 mm .The same results were recorded in limestone mixes except that the best one of them was LIM-3B mix where the max rut depth was 3.02mm . However the LIM-Bailey had a relatively high rut resistance compared with the other LIM mixes where the max rut depth value was 3.19mm.Dense graded mixes of dolomite and limestone were showed more rutting, especially LIM-4B and LIM-4C mixtures showed unacceptable results with the max rut depths of 9.63mm and 8.02mm respectively.(>7 mm)

6. Evaluation of rut depth and it's correlation with stability, flow, stiffness index, and VMA

Figures (5) to (8) show the effect of stability, stiffness index ,flow, and VMA on rut depth and their correlations for:

- All 12 mixtures except LIM 4B and LIM 4C.
- Open and coarse mixtures (2C,3B,3D and Bailey mixes)

6.1 Stability versus rut depth

Figures (5a) shows an increase in stability values while slightly decrease in rut depth with very low correlation ($R^2 = 0.07$). As these mixes are different in their performance against rutting, therefore; the data of coarse and open mixes were separated and then the relationships was redrawn in figure (5b). It is clear from this figure that the rut depth decreases with an increase in stability with a relatively high correlation ($R^2 = 0.2$). Therefore, it was concluded that stability is not the only major parameter to control rutting potential.

6.2 Flow versus rut depth

The relationships between flow and rut depth were plotted in Figure (6a, b). It can be concluded that, there is almost no correlation between them in all mixes (figure (6a), while the rut depth increases with an increase in flow in case of discarding the results of dense mixes, with also a low correlation ($R^2 = 0.13$) "figure (6 b)". It can be also concluded from previous figures that, the flow results alone also are not a good indicator for the rut performance

6.3 Stiffness index versus rut depth

Stiffness index is the ratio of stability divided by flow value**.** It can be noticed that the stiffness index also slightly increases with a decrease in the rut depth, with very low correlation figure (7a). However, the same relationship could be obtained in case of discarding the results of dense mixes, with a relatively high correlation ($R^2 = 0.3$) figure (7b). It can be also concluded that the stiffness index is not also a good indicator to represent the rut performance of HMA.

6.4 VMA versus rut depth

The same results of flow are concluded as there is almost no correlation between VMA and rut depth in case of all mixtures figure (8a).While the rut depth increases with an increase in VMA in case of discarding the results of dense mixes, with a relatively high correlation (R^2 = 0.23)"figure (8b)". It can be also concluded from the previous figures that, VMA results alone are not a good indicator for the rut performance.
These results are in agreement with Shiau, et al, (1997) **[10]** who concluded that, "the Marshall stability and flow could not evaluate rutting resistance for different aggregate gradations, and the VMA was better than the dense grade mixture to resist rutting". They are also in agreement with Abukhettala (2006) **[1]** , who stated that there is no correlation between stability, flow and rutting, therefore, stability, flow and stiffness cannot be used to predict rutting of the new Malaysia HMA mixtures**.**
In contrast Brown, et al, (1989) **[4]** concluded that Marshall flow is a good indicator for rutting. Also Ahmed, et al, (2011) **[2]** stated that there is a strong correlation between stiffness factor and rut depth from wheel tracking test when tested between 40°C and 50°C. Randolph, et al, (1996) **[9]** concluded that the Marshall stability/flow ratio produced the strongest correlation with rutting for all HMA mixture properties with R^2 values of 0.528. These results confirmed the obtained results in case of stability and flow with different values of R2. Brown, et al (1989) carried out their work on asphalt concrete cores hence, there are other factors may affect these results. Therefore, the authors believe that the rut depth depends on several parameters rather than stability, flow, stiffness index , and VMA only.

7. Evaluation of rut depth using Bailey parameters (Ratios)

After blending the aggregates by using Bailey Method procedures for two mixes and the Bailey ratios for them were calculated, then they were compared with the Bailey recommended ranges. The calculations for the other mixes could be calculated too. These ratios may be useful to evaluate rut depth of mixes, to evaluate packing of the portions of the combined aggregate gradation and to predict other properties of HMA such as VMA. Three ratios were defined: the coarse aggregate ratio (CA_{Ratio}), the coarse portion of fine aggregate ratio (FAc_{Ratio}), and the fine portion of the fine aggregate ratio ($FA_{f\ Ratio}$). Bailey ratios of all mixes were calculated then collected and presented as shown in table (3) and figures (9), (10) and (11). The table also shows "NMPS" for each mix and recommended ranges (R.Ranges) of Bailey ratios according to Bailey procedures.

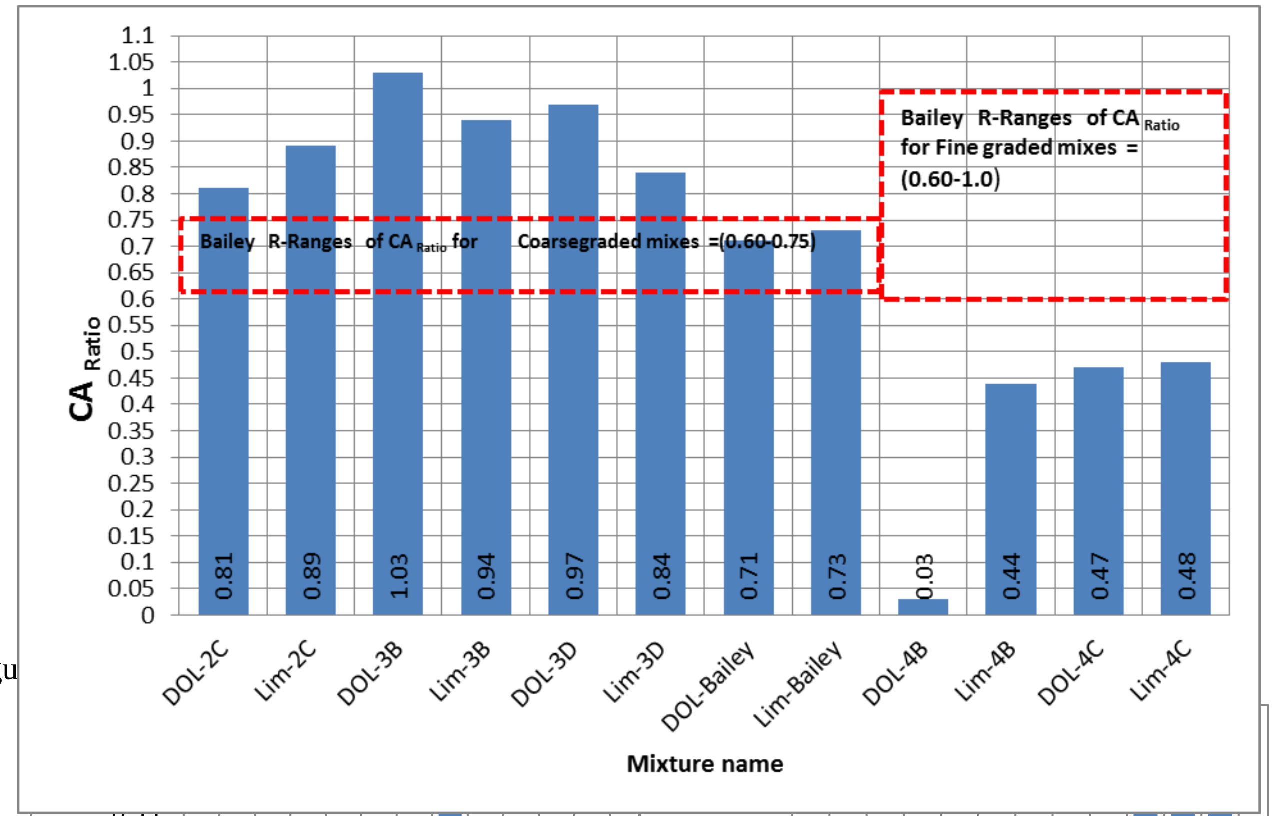
Table (3) Bailey ratios of DOL and LIM mixtures and Bailey recommended ranges

Mixture name	NMPS (mm)	Bailey Ratios and their recommended ranges"R.Ranges"					
		CA Ratio	R.Ranges	FAc Ratio	R.Ranges	FAf Ratio	R.Ranges
DOL-2C	19.0	0.81	0.60-0.75	0.46	0.35-0.50	0.43	0.35-0.50
DOL-3B	19.0	1.03	0.60-0.75	0.48	0.35-0.50	0.45	0.35-0.50
DOL-3D	19.0	0.97	0.60-0.75	0.44	0.35-0.50	0.37	0.35-0.50
DOL-4B	12.5	0.03	0.60-1.0	0.36	0.35-0.50	——*	0.35-0.50
DOL-4C	19.0	0.47	0.60-1.0	0.46	0.35-0.50	0.69	0.35-0.50

DOL-Bailey	19.0	0.71	0.60-0.75	0.47	0.35-0.50	0.43	0.35-0.50
Lim-2C	19.0	0.89	0.60-0.75	0.35	0.35-0.50	0.44	0.35-0.50
Lim-3B	19.0	0.94	0.60-0.75	0.38	0.35-0.50	0.38	0.35-0.50
Lim-3D	19.0	0.84	0.60-0.75	0.39	0.35-0.50	0.39	0.35-0.50
Lim-4B	19.0	0.44	0.60-1.0	0.65	0.35-0.50	0.65	0.35-0.50
Lim-4C	19.0	0.48	0.60-1.0	0.46	0.35-0.50	0.67	0.35-0.50
Lim-Bailey	19.0	0.73	0.60-0.75	0.41	0.35-0.50	0.47	0.35-0.50

***No $FA_{f\ Ratio}$ for NMPS=12.5mm.**

Surman Journal for Science and Technology
Vol.02, No.3, Dec 2020, pp. 047 ~ 062



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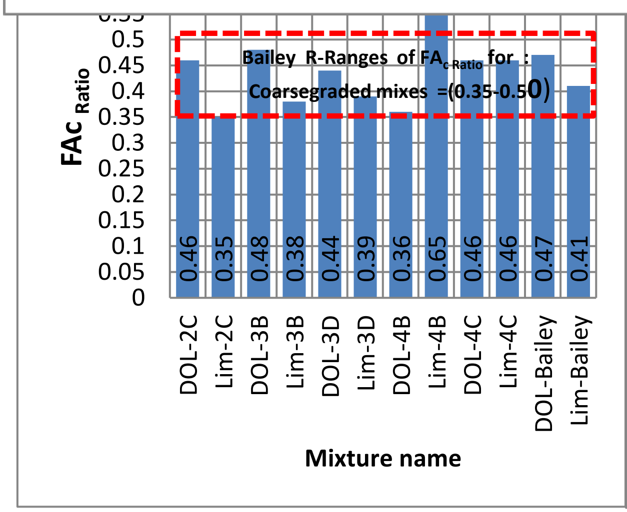

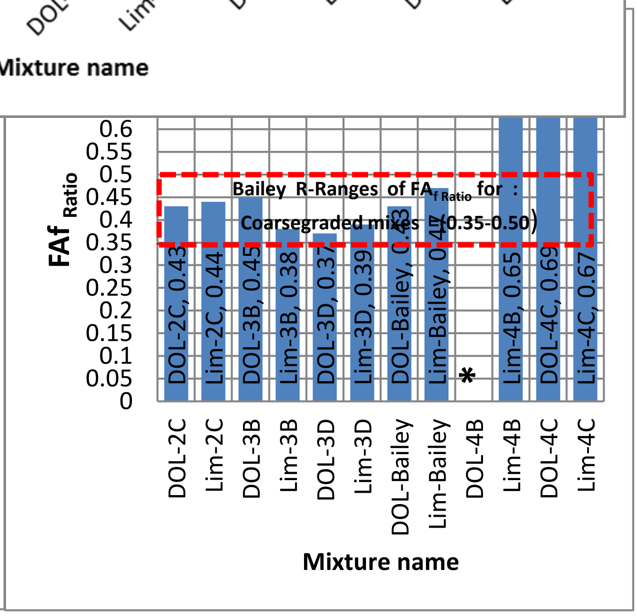

Figure (10) Calculated Bailey FA_c Ratio for all the mixes and Bailey recommended ranges.

Figure (11) Calculated Bailey FA_f Ratio for all the 12 the 12 mixes and Bailey recommended ranges.

Finally: The aggregate gradation curve had a significant effect on laboratory permanent deformation properties and field compaction. Mixes with coarser gradation produced more resistance to rutting than mixes with finer gradations under WTT and, an increase in the fine aggregates content had an adverse effect on the laboratory permanent deformation properties. These conclusions are in agreement with Randolph, et al, (1996) **[9]** and the percentage of crushed coarse particles had a significant effect on laboratory permanent deformation properties. Also these results are in agreement with Gregory, et al, (1999) **[7]** and Hafeez, et al, (2009) **[5]** who found that mixes with coarser gradation produced more resistance to rutting than mixes with finer gradations.

8. Conclusions

Based on the results and discussions of the test data, the following conclusions can be drawn:

- There is a good relationship between aggregate gradation and HMA properties and permanent deformation "Rutting" especially when the gradation is quantified by the Bailey aggregate ratios.
- Mixes with coarser gradation (3B, 3D and Bailey mixes) produce more resistance to rutting than dense gradation mixtures (4B and 4C-mixes) or open gradation mixtures (2C-mixes) under WT machine, but may be exposed to difficult field compaction, if the aggregate ratios gradations of these mixes are not controlled.
- An increase in fine aggregates (sand) caused an adverse effect on the laboratory permanent deformation properties.
- Bailey method is a useful tool in redesigning and evaluating aggregate blends particularly when combined with engineering experience.
- Controlling aggregate ratios gradations could control anticipated mix properties and predict permanent performance of HMA.
- The main limitation of the Bailey method is only consider aggregate size and pays little attention to other aggregate properties (e.g, shape, Strength, surface of the particles, type and amount of compaction energy, …etc.) .This limitation is observed in rutting performance variations when the materials were changed from dolomite to limestone of the same type of gradation.
- There is no strong correlation between stability, flow and stiffness index and rut depth. Therefore; they cannot be used to predict rutting potential of the HMA mixture.

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