

"Controlling Rutting Performance of Hot Mix Asphalt"

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ABSTRACT

The Bailey Method provides a set of tools for the design and the evaluation of aggregate packing and voids of asphalt concrete grading while maintaining appropriate mixture workability and durability.

The objectives of this research were using "Bailey Method" to evaluate using of Marshall Stability, flow, and stiffness index to predict rutting, and to investigate the Bailey ratios for all different blends for prediction of rutting. Two types of aggregate blends were prepared. Different aggregate gradations were used in this research included coarse, open and dense gradations then rutting performance was evaluated. The results proved that Bailey method is a useful tool in evaluating aggregate blends. Mixes with coarser gradation produced more resistance to rutting than dense or open gradation mixtures. Controlling aggregate ratios gradations could control anticipated mix properties and predict permanent performance of HMA.

Key words: Bailey methods, Hot mix asphalt, rutting, wheel tracking, Marshal.

1. Introduction

The aim of HMA design is to find the optimum combination of aggregate, void spaces, and asphalt binder to ensure that the pavement exhibits the desired performance and durability properties. Aggregate grading is an essential property of bituminous mixtures, as it can be related to many aspects of mixtures performance in the field, such as durability and resistance to permanent deformation. Such complex circumstances make pavement material performance assessment an aspect of great importance for any project. Selection of proper pavement material of adequate structural performance may increase the effective life of the structure, while requiring less maintenance and repair measures, Tabatabaee, 2012).

Brown and Cross (1989) suggested that Marshall flow is a good indicator of rutting potential. In acceptable mix design and construction, Marshall flow should be less than 16, and mixtures with Marshall flow exceeding 16 tend to have a higher amount of rut (Abukhettala, 2006). Stiffness Index, which is Marshall stability divided by Marshall flow, estimates load deformation characteristics of the mixture, and indicates the material resistance to

pavement rutting (Asphalt Institute, 2001). A mixture with high Marshall stiffness is a stiffer mixture, that can resist pavement rutting (Abukhettala, 2006).

Voids in the mineral aggregate (VMA) requirements are specified to allow what is considered the proper balance of air voids and asphalt binder in the mixture to ensure optimum pavement performance, (Asphalt Institute, 2001). The lower (VMA) values being obtained by mixture designers is related to the recommended use of coarse graded mixtures, (Kandhal et al 1998). Of great debate amongst designers and researchers is the validity of the (VMA) requirements set by the Asphalt Institute and other governing bodies. This debate is a result of insufficient research correlating (HMA) pavement performance and (VMA) (Kandhal and Chakraborty 1996). Asphalt Binder coats the aggregate particles, which aids in a tighter compaction than if no binder was present, thereby decreasing (VMA) (Foreman, 2008).

2. Rutting Problem

Pavement rutting is one of the most serious types of pavement distress that affect road safety and ride quality, (Naiel, 2010) when it reaches critical depths (Ali, 2006). The presence of rutting on flexible pavement layers has always been a problem adversely affecting the performance of pavements and reduces the life of pavement. Further, the decreased thickness in the rutted

portions may accelerate fatigue cracking. Modeling rut progression and predicting its occurrence helps engineers to design pavements in such a way that the pavement can avoid excessive rutting in its expected service life. The possible causes of pavement deformation include inadequate pavement thickness, poor compaction, and low stability of mix and settlement of layers, Shafie (2007).

Rutting does not occur only in (HMA) layers, but can also occur in any of the underlying pavement layers. However, in most pavements, rutting appears only as a change in surface profile and it is often contributed to surface instability, (Archilla and Madanat, 2001; Chen et al 2003; Fwa et al 2004; Zhou et al 2004). In addition, eliminating rutting development in (HMA) pavements have enormous economical benefits by reducing maintenance costs and extending the service life of the highway system. Repeated Load Permanent Deformation (RLPD) test as a laboratory procedure can be used for evaluating the resistance of HMA mixtures to rutting, (Rodezno 2010).

Gradation is considered the most important property of aggregates that influences the performance of asphalt pavements. So, in this research, the effect of this property "Gradation of aggregates" on rutting performance was evaluated

3. The Bailey Method

After decades of use, a lot of valuable experiences with Marshall mix design method have been obtained. 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 presents a model of an aggregate matrix based on particle compaction as influenced by particle size distribution. Also provides a set of tools for the design and the evaluation of aggregate packing and voids of asphalt concrete grading while maintaining appropriate mixture workability and durability, The basic principles of the Bailey Method have been empirically developed, therefore its parameters and rules

are strongly based on sieves and aggregate sizes (Graziana et al 2012). The procedures are simple and straight forward and require no fabrication of samples because it requires only aggregate data and grading. The evaluation portion of the method makes general predictions about the relative (VMA) and comparability. However, since the Bailey Method only looks at particle size and includes very little about other aggregate properties that significantly affect the behavior of a blend,

4. 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. The bailey method provides this needed assistance to the designer to provide resistance to rutting and long

using different gradations. It was found that indirect tensile strength of the mixture was sensitive to aggregate gradation characteristics. Generally, the finer aggregate gradation had the higher indirect tensile strength, (Park, 2008).

One of the contributors to rutting in (HMA) pavements is excessive asphalt content which leads to the loss of interlock between aggregate so that traffic loads will be bore by asphalt not aggregate. Increasing the design asphalt content will decrease the shear resistance of mixtures to induce lateral movement of materials. An increase in the viscosity of the asphalt cement at the same pavement temperature or using rubber and polymers (Ouf et al. 2010) can improve rutting resistance. Rutting not only reduces the useful service life of pavements, but it may also affect basic vehicle handling maneuvers, which can be hazardous to highway users (Liseane et al. 2010).

such as texture and shape, exact results cannot be expected, (Rivera 2008).

The goal of Bailey Method is to design a blend that uses the aggregate particles efficiently, meaning that there is a balance of coarse and fine particles. Such a balance allows the coarse aggregate to interlock, meaning each (relatively) large stone is transferring its load to as many other large stones as possible, and allows the fine aggregate to fully support the coarse aggregate by filling the void spaces fully without over filling them, which would push the coarse particles apart. A balanced blend should be strong against rutting and still be easy to compact (Vavrik, et al 2002).

The basic principle of the Bailey Method is that maximum compressive strength of an asphalt mix is best achieved when there is stone to stone contact of as many aggregate particles as possible. This allows a spreading of the load from the vehicle tire to the sub layers beneath the pavement through as many particles as possible. The proper stone to stone contact is achieved when the aggregate blend has a balance of coarse and fine particles. This means that the coarse particles are all touching with the voids between them neither under nor over filled with fine particles (Vavrik, et al 2002).

durability or long term performance with the available aggregates. The Bailey method allows the designer to select an aggregate skeleton that is 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.

5. 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?).

6. Materials

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 coarse aggregate (CA2) larger than 9.5mm and smaller than 25mm, while the second is coarse aggregate (CA1) larger than 2mm and smaller than 9.5mm.

Two additional materials to enhance the grading 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.).

7. Performance test

During the design process of asphalt pavements different environmental and traffic loading conditions should taken into account. It should be able to resist such external factors and as well as climatic conditions without being damaged,

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.

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).

(Karacasuaa 2012). To evaluate the performance of all mixes, Wheel Tracking test (WTT) were conducted on the HMA and the engineering properties were determined and presented. Figures (1) and (2) show the steps which are conducted in this study.

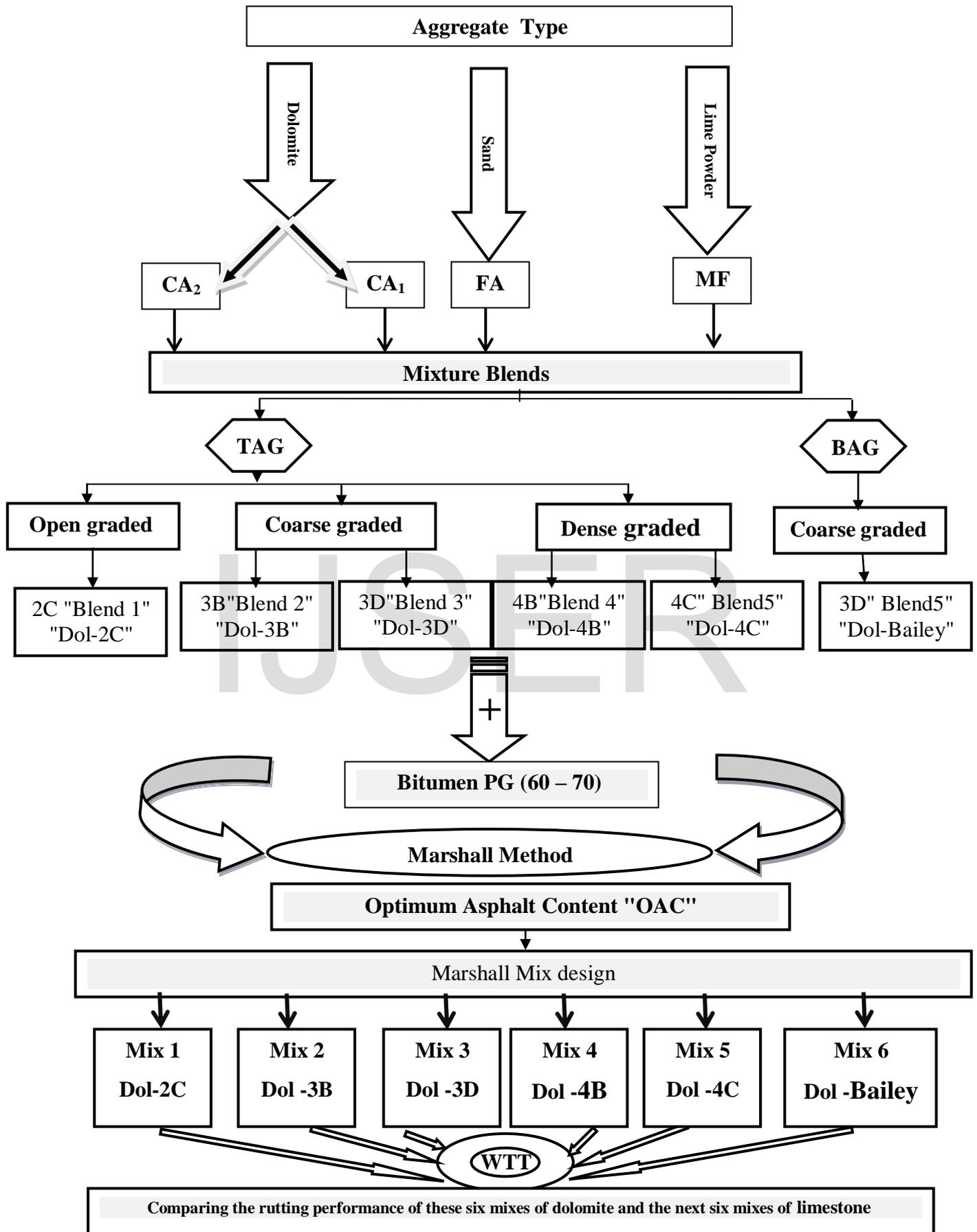


Figure (1): Schematic diagram of the experimental program for DOL-MIX.

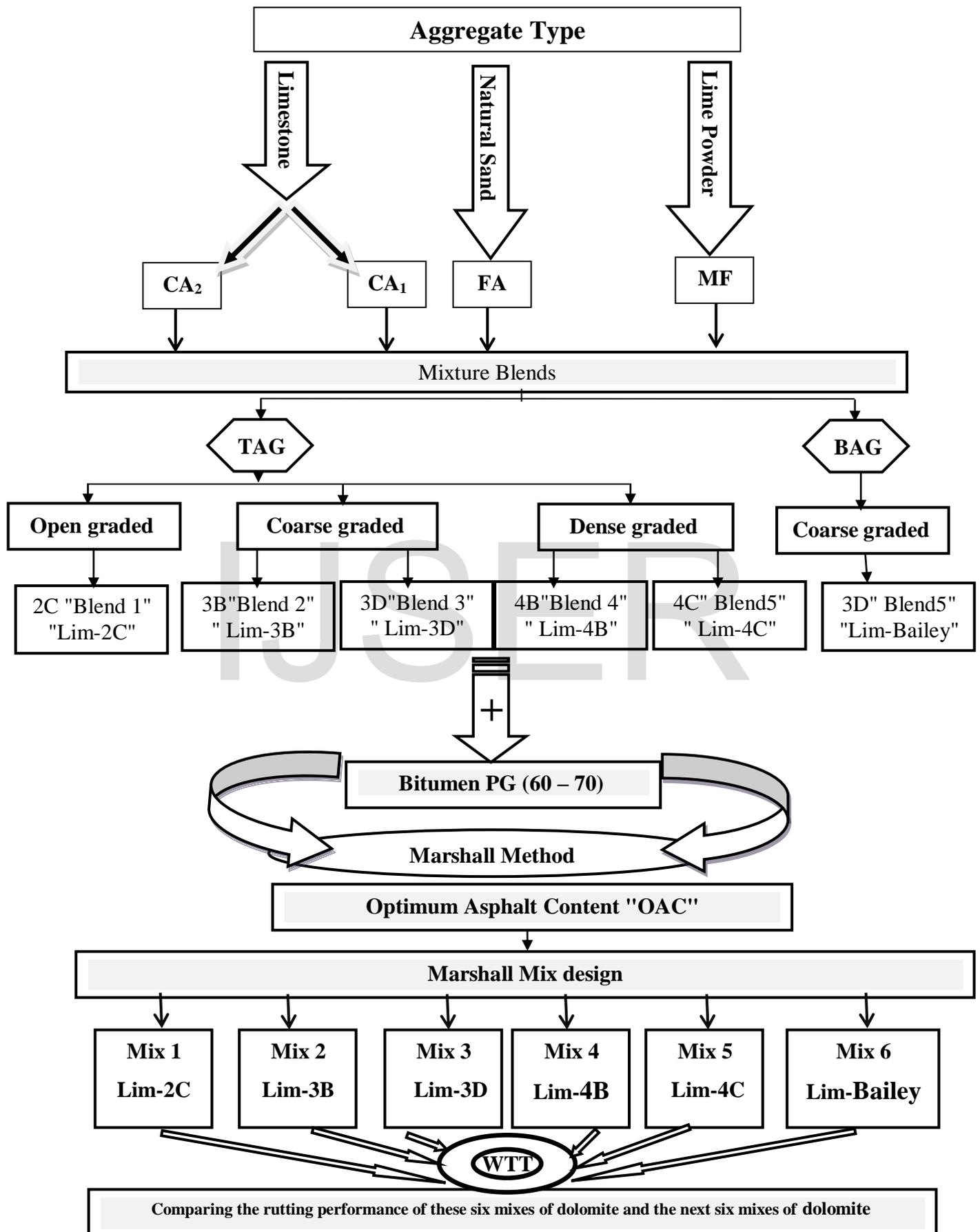


Figure (2): Schematic diagram of the experimental program for LIM-MIX.

8. Results

The preparation of the molds for WTT was carried out for each mixture with the same percentages of "OAC"; then it was mixed and compacted for testing in the Wheel Tracking machine for rutting evaluation. Figures (3) and (4) show the WTT

results. Finally, stability, flow, stiffness, VMA and rut depth values for each mix at OAC were collected. The 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).

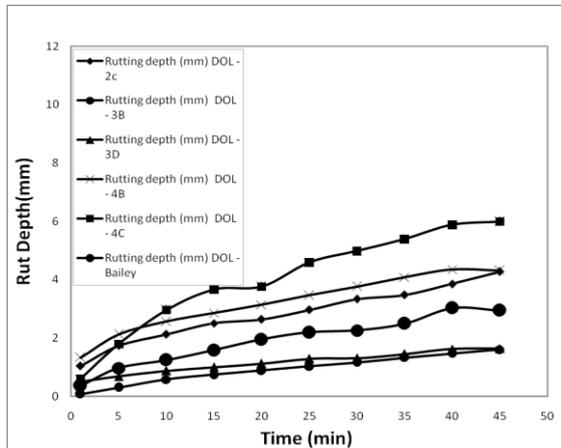
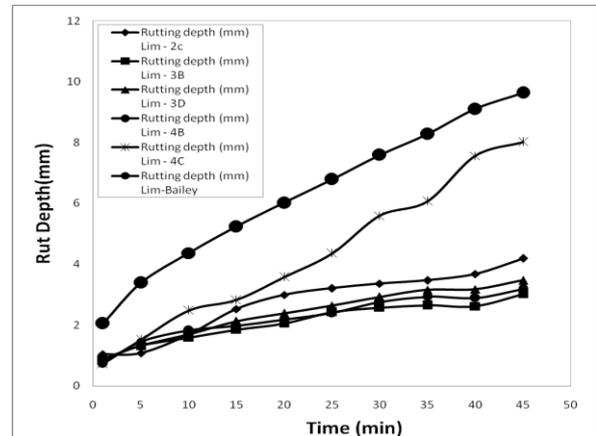


Figure (4) Relationship between time (min) and max rut depth (mm) for the six LIM-mixes



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

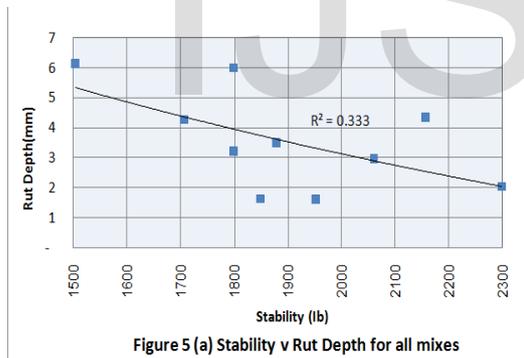


Figure 5 (a) Stability v Rut Depth for all mixes

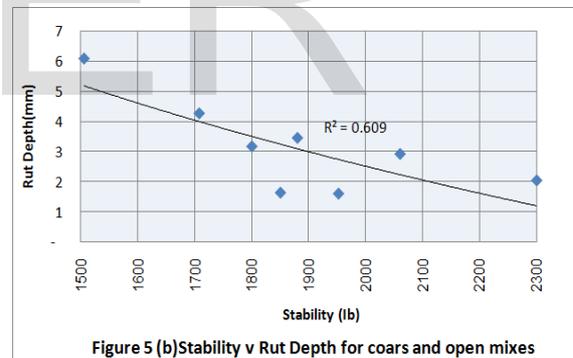


Figure 5 (b) Stability v Rut Depth for coars and open mixes

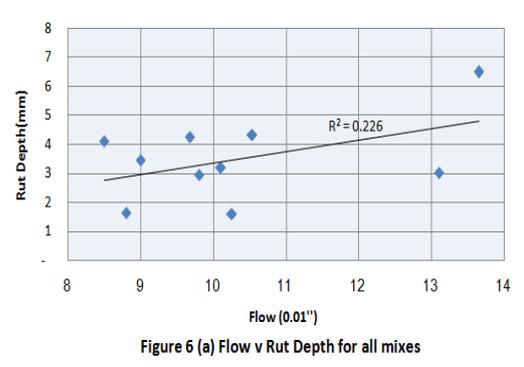


Figure 6 (a) Flow v Rut Depth for all mixes

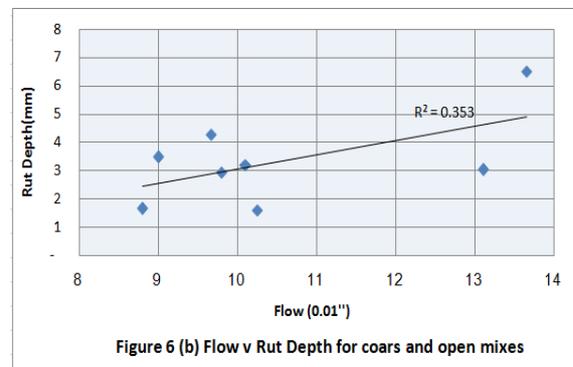
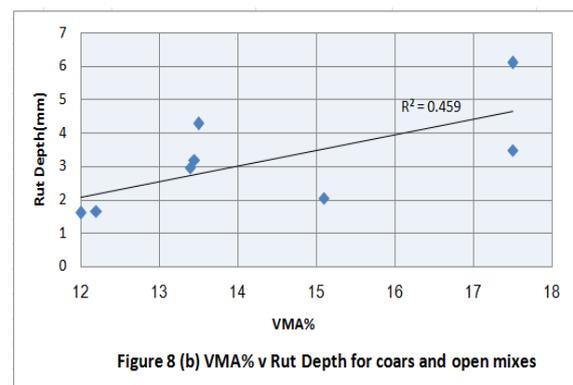
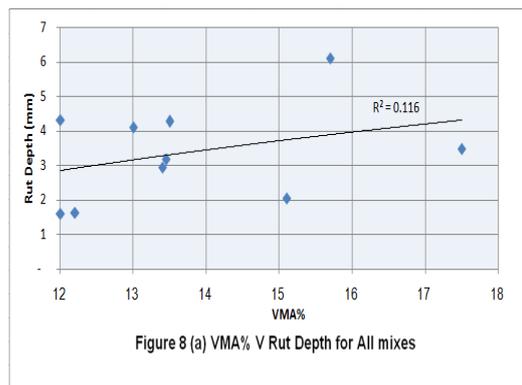
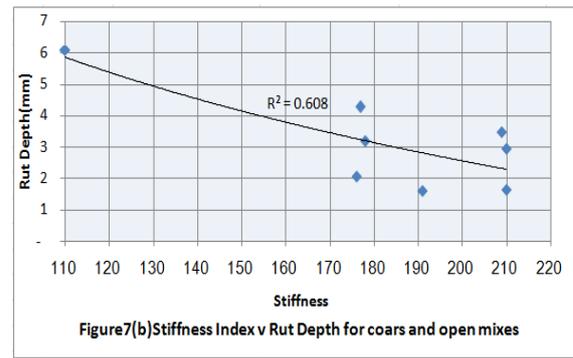
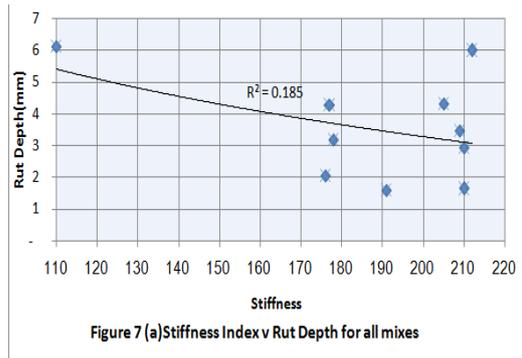


Figure 6 (b) Flow v Rut Depth for coars and open mixes



In figures 3 and 4, dolomite mixtures with higher 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

lime stone 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 3.19 mm. Dense graded mixes of dolomite and limestone were showed higher rutting, especially LIM-4B and LIM-4C mixtures that showed unacceptable results with the max rut depths of 9.63mm and 8.02mm respectively. (>7 mm).

9. Evaluation of rut depth and it's correlation with stability, flow, stiffness, 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 which were damaged during preparation.
- Open and coarse mixtures (2C,3B,3D and Bailey mixes)

9.1 Stability versus rut depth:

Figures (5a) shows an increase in stability while slightly decrease in rut depth with low correlation ($R^2 = 0.33$). 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 was clear that the rut depth decreases with an increase in stability with a relatively higher correlation (R^2

$=0.609$).

9.2 Flow versus rut depth:

The relationship between flow and rut depth was plotted in Figure 6. It can be concluded that, there is low correlation between them in all mixes ($R^2 = 0.226$) "figure (6a)", while the rut depth increases with an increase in flow in case of discarding the results of dense mixes, with a relatively higher correlation ($R^2 = 0.353$) "figure (6 b)".

9.3 Stiffness index versus rut depth:

The stiffness index slightly increases with a decrease in the rut depth, with low correlation ($R^2 = 0.186$) "figure (7a)". However, the same relationship could be obtained in case of discarding the results of dense mixes, with a relatively higher correlation ($R^2 = 0.608$) "figure (7b)".

9.4 VMA versus rut depth:

Also, almost no correlation between VMA and rut depth in case of all mixtures ($R^2 = 0.116$) "figure (8a)". While rut depth increases with an increase in

VMA in case of discarding the results of dense mixes, with a relatively high correlation ($R^2 = 0.459$) "figure (8b)".

From the previous results, it can be concluded that, stiffness, flow, stiffness index, VMA results only are not an excellent indicators for predicting rutting performance. Shiau et al, (1997) and Abukhettala (2006) concluded that, Marshall stability and flow only could not precisely predict rutting in HMA mixtures. In contrast Brown and Cross (1989) concluded that Marshall flow is a good indicator for rutting while, Ahmad et al (2011) found a strong correlation between Marshal stiffness and rut depth. These results confirmed the obtained results in case of stability and flow. The authors believe that the rut depth depends on several parameters rather than stability, flow, and stiffness index only.

It has been recognized that aggregate gradation, shape, texture, the structure of the aggregate, fine aggregate (dust) angularity and proportion of the mixture greatly affects mixture performance and packing characteristics of HMA, (Coree, et al 1999, Asphalt Institute, 1995; Coree and Hislop, 2001). Angularity is one of the important properties in order

to provide an adequate internal friction, and therefore rutting resistance, occurs within the aggregate particles HMA, (Asphalt Institute, 2001).

Angular and rough textured aggregates have much greater particle to particle contact than rounded and smooth textured aggregate. Thus, when high resistance to shearing forces is required, rough, angular shaped aggregates are used. This influence particle contact not only in the coarse aggregate, but also in rough, angular fine aggregates. When highly stable aggregate mixtures are needed, it is recommended that both coarse and fine aggregates must be angular and rough surface textured crushed stone, Topal and Sengoz (2005). They also showed that the more aggregate angularity the less susceptible to rutting. Flaky and elongated aggregates are not desirable in HMA, as they tend to break and slide easily under stresses caused excessive rutting, Other aggregate properties such as mineralogical properties of aggregate, surface texture, hardness, absorption, affinity for asphalt cement, etc must also be taken into account for evaluating the rutting performance, (Topal and Sengoz, 2005).

10. Evaluation of rut depth using Bailey parameters (Ratios):

After blending the aggregates using Bailey Method procedures for the 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 for mixes, to evaluate the 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 ($FA_{c Ratio}$), 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 (1) and figures (9), (10) and (11). The table also shows "NMPS" for each mix and recommended ranges of Bailey ratios.

Table (1) 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	$FA_{c Ratio}$	R.Ranges	$FA_{f Ratio}$	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.

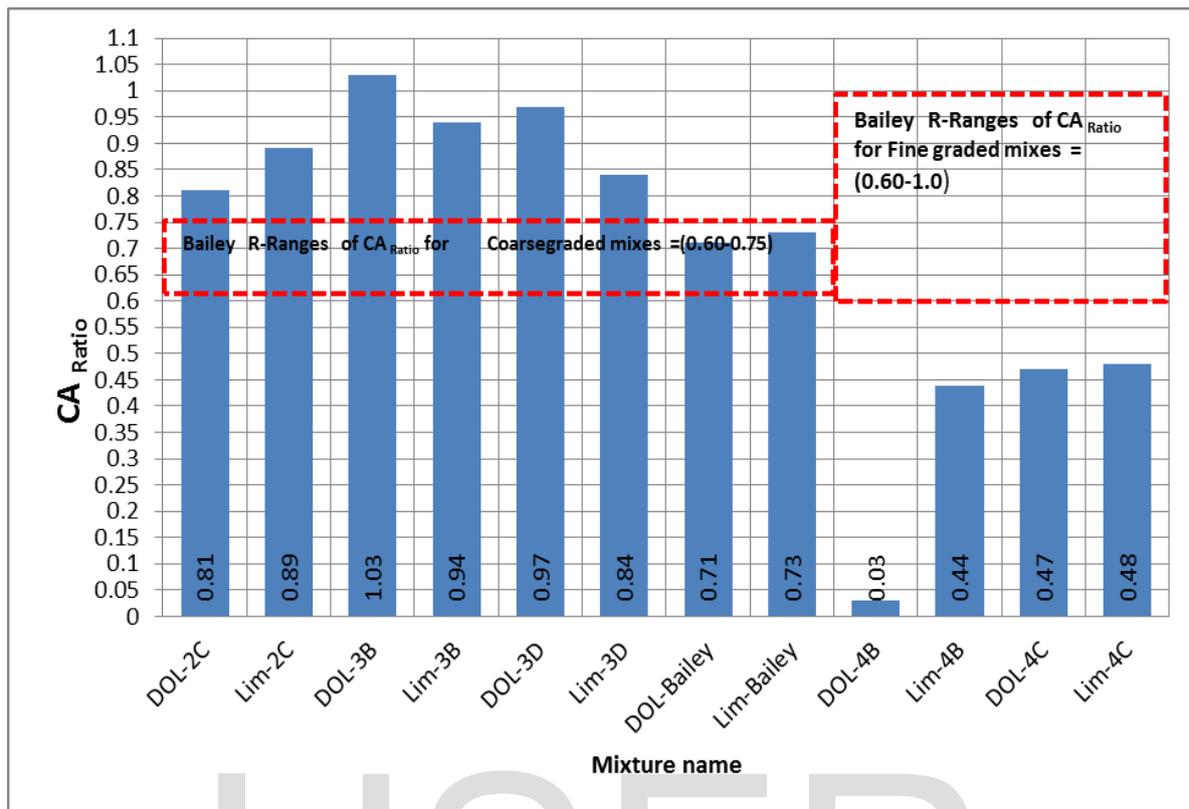


Figure (9) Calculated Bailey CA ratios for all the 12 mixes and Bailey recommended ranges

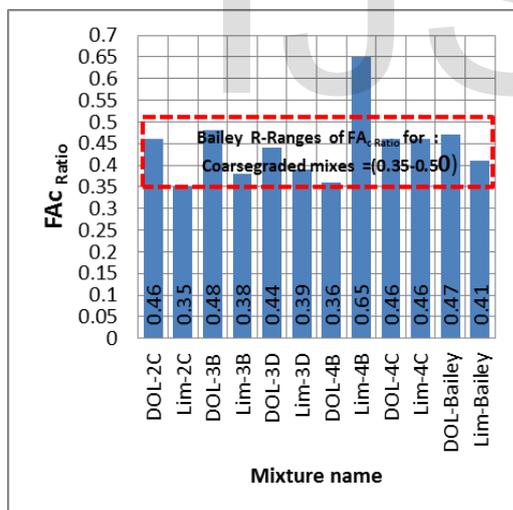
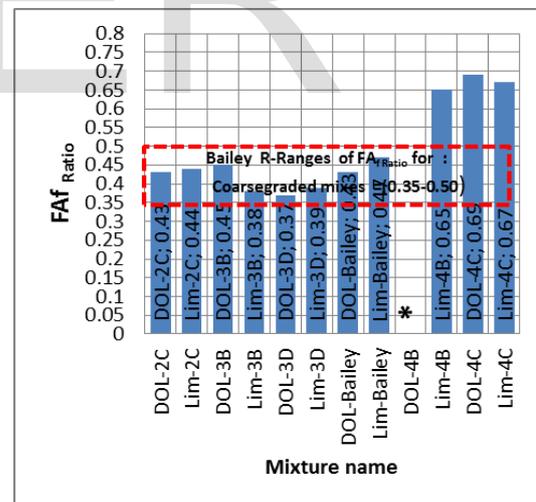


Figure (10) Calculated Bailey FAc Ratio for all mixtures and Bailey recommended ranges .

*no FAc Ratio (12.5NMPs)



Figure(11) Calculated Bailey FAf Ratio for all mixtures 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

11. Conclusions

The main conclusions are:

- Mixes with coarser gradation (3B, 3D and Bailey mixes) produced more resistance to rutting than dense gradation mixtures (4B and 4C-mixes) or open gradation mixtures (2C-mixes) under WT machine.
- Bailey method is a useful tool in 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 limitations of the Bailey method is only considering aggregate size and gradation

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