# Impact of Aggregate Gradation and Type on Hot Mix Asphalt Rutting In Egypt

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## ABSTRACT

**Rutting of flexible pavement is considered one of the major pavement distresses noted around the world and in Egypt. Many investigators showed at about 55 to 80% of rutting occurred in the surface layer. Rutting of asphalt surface layer may be due to many causes happened during construction phase and service phase. The main objectives of this research are to evaluate the impact of aggregate gradation and type on hot mix asphalt (HMA) rutting potential in Egypt, understand the effect of aggregate properties on Marshall mix properties and evaluate the relation between mix properties and rutting potential of HMA.**

**Experimental program was designed and conducted on common asphalt paving mixtures of different aggregate sources and gradations. Samples prepared at optimum asphalt content, as defined by Marshall method, were tested using wheel track test and permanent deformation was measured.**

**Study results showed that rutting resistance of asphalt paving mixes is affected by the mix gradation and type of aggregate. Coarser gradation (3A) had the highest resistance to rutting for all types of aggregate, while open graded mixes (2C) had the lowest resistance. Dolomite had the highest resistance for all types of gradations. Marshall flow had the highest linear correlation with rutting, with coefficient of determination ($R^2$) of 0.74.**

## I. Introduction and Background

The performance of hot mix asphalt (HMA) is mainly function of the characteristics of its constituents: asphalt binder and aggregate; along with the quality of the construction process [1-3]. The major distresses in flexible pavements are rutting, fatigue cracking and low temperature thermal cracking. Rutting, the load-induced permanent deformation of a flexible pavement, is probably considered the most important distress that contributes to the failure of a pavement. It is caused by the permanent deformation that develops gradually in the longitudinal direction under the wheel paths due to high traffic loads associated with high field temperatures [3]. Depending on the magnitude of the load and the relative strength of the pavement layers, permanent deformation can occur in the subgrade, the base, or the upper hot mix asphalt (HMA) layers [4]. In a survey that covered all of the USA, rutting due to permanent deformation in the HMA layer was found to be the most common distress [5].

Rutting phenomena has gained widespread attention in Egypt as well as most tropical countries because of increasing of roads that early suffer from rutting. Gab-Allah [6] found that 22.8% on the average of the total deduct points of 19 distresses used for pavement conditions rating was caused by rutting. Many investigators deduced that asphalt surface layer has contributed the most amount of the total pavement rutting [5-8]. In the study [6], it was showed that about 56 to 80% of the total pavement rutting occurred in asphalt surface layer. Limiting rutting of asphalt pavements during the design and construction phases was the goal of many studies.

## II. Effect of Aggregate gradation and type on rutting of HMA

El-Basyouny and Mamlouk 1999 evaluated the effect of aggregate gradation on the rutting potential of Superpave mixes [10]. They found that both the aggregate gradation and aggregate nominal size affected the rut depth for pavement section as estimated by the VESYS-3AM software. Mixtures prepared using aggregate gradation passing below the restricted zone (on the Superpave gradation chart) had better resistance to rutting as compared to those made from aggregates with gradation passing through or above the restricted zone [10,11]. This means that coarser gradations are expected to perform better than finer gradation. The limitation of this study was that the comparisons were made based on rut depth predicted by model rather than measured rut depth [11].

Other researchers evaluated two mixtures made from aggregates with different gradations [11, 12]. The aggregate for first mixture had an S-shaped gradation that stays below the maximum density line and passes below the restricted zone. The second mixture was made from aggregate with finer gradation that stayed above the maximum density line and above the restricted zone. Other mixtures with aggregate gradations 5 to 20% coarser, as measured on the 4.75 mm sieve, than the fine and coarse mixtures were also evaluated. The mixtures were evaluated for permanent deformation using Asphalt Pavement Analyser

(Georgia rut tester) [11, 12]. They concluded that the finer gradation had better resistance to permanent deformation.

Carpenter and Enockson concluded that majority of the rutting problem can be attributed to aggregate gradation based on evaluating 32 overlay projects in Illinois, USA [11, 13]. Oliver et al. reported that aggregate gradation has a significant influence on rutting resistance based on field and laboratory study on several mixtures in Australia [11, 14].

Other researchers have reached different conclusions. Brown and Cross [15] indicated that aggregate properties have little effect on rutting when voids are less than 2.5%. For percentage of voids greater than 2.5, Brown and Cross claimed that, it is the fine aggregate angularity and not the gradation that has a significant influence on rutting resistance [11, 15]. Barksdale reported that permanent deformation in dense graded asphalt concrete was not sensitive to gradation of aggregates [11]. Data from the 2000 National Center for Asphalt Technology (NCAT) Test Track indicated that fine and coarse gradations had the same rut resistance [1].

Quadis and Shweily found that unconditioned HMA specimens prepared using Basalt aggregate had better resistance to creep compared to those prepared using Limestone. However, after conditioning under water, mixes prepared using Basalt were less resistant to creep compared to those prepared using Limestone aggregate [16].

## III. Problem Statement and Research Objectives

Aggregate presents major portion of asphalt concrete. It was found that researchers have come to different conclusions with regard to the effect of aggregate gradation on resistance to rutting of asphalt mixtures.

The main objectives of this research are to:

- Evaluate the impact of aggregate gradation and type on Marshall mix properties of hot mix asphalt (HMA).
- Evaluate the impact of aggregate gradation and type on the rutting potential of HMA in Egypt.
- Investigate the relation between Marshall mix design criteria and HMA rutting.

## IV. Experimental Program

Three types of aggregate that are typically used to produce hot mix asphalt in Egypt were used in this study. They are:

- Crushed Basalt from “Km. 102, kena-Safaga highway,
- Crushed Dolomite from “Ataka” quarry, Suez Governorate and
- Crushed Limestone from “Tora” quarry, Cairo Governorate.

The properties of these types of aggregate were evaluated. Table (1) shows these tests results. Siliceous sand was used as a fine aggregate in all designed asphalt concrete mixes, it had a specific gravity 2.65 gm/cm$^3$. The Limestone powder passing sieve No.50 was used as a mineral filler in all designed mixes. This Limestone powder is free from any impurities such as silt or clay. It is non-plastic material and has a specific gravity of 2.75 gm/cm$^3$. One source of asphalt was used in this study (Suez asphalt cement), it has a penetration of 68 at 25° C, softening point 52$^o$ C, kinematic viscosity 374 centistokes at 135° C.

Four gradations (according to Egyptian Specification) [17] of aggregate were used in preparing the hot mix asphalt samples, this included:

- 3A: Coarse gradation
- 5A: Fine gradation
- 2C: Open gradation
- 4C: Dense gradation (currently most used gradation in Egyptian surface mixes)

Figure 1 present the gradation of all of the four gradations used in the study. Figure 2 summarize the experimental design of this research.

The mix design was performed using Marshall design method because it is the current method of mix design in the General Authority of Roads, Bridges, and Land Transportation (GARBLT) specification in Egypt. The optimum asphalt content is defined following asphalt institute method (2) as the average of 3 values (asphalt content at 4% air voids, asphalt content at maximum stability and asphalt content at maximum density).

Rutting resistance of the designed mixes was evaluated by wheel tracking test [18]. The samples of wheel tracking test were prepared to have asphalt contents and maximum unit weights equal to optimum asphalt content and maximum unit weight of Marshal mix design. The wheel tracking machine consisted of loaded rubber-tired wheel, with a diameter of 20 cm and 5 cm width. The applied load was 53.5 kg. The wheel is rigidly restrained over a movable table. The table moved over a distance of 25.5 cm at a rate of 42 passes per minute. The total test time was 60 minutes (total of 42*60 = 2520 pass).

**Table 1: Properties of Coarse Aggregate Materials.**

| Test Name | Results | | | Specification Limits |
|---|---|---|---|---|
| | Basalt | Dolomite | Lime stone | |
| Bulk specific gravity | 2.93 | 2.605 | 3.183 | - |
| Saturated surface dry specific gravity | 2.699 | 2.643 | 2.339 | - |
| Apparent specific gravity | 2.711 | 2.705 | 2.588 | - |
| Los Angeles abrasion 100 revolutions (%) | 4 | 5.5 | 10 | ≤ 10 |
| Los Angeles abrasion 500 revolutions (%) | 16 | 25.5 | 40 | ≤ 40 |
| Water absorption (%) | 0.25 | 1.45 | 5 | ≤ 5 |
| Stripping (%) | >95 | >95 | >95 | >95 |

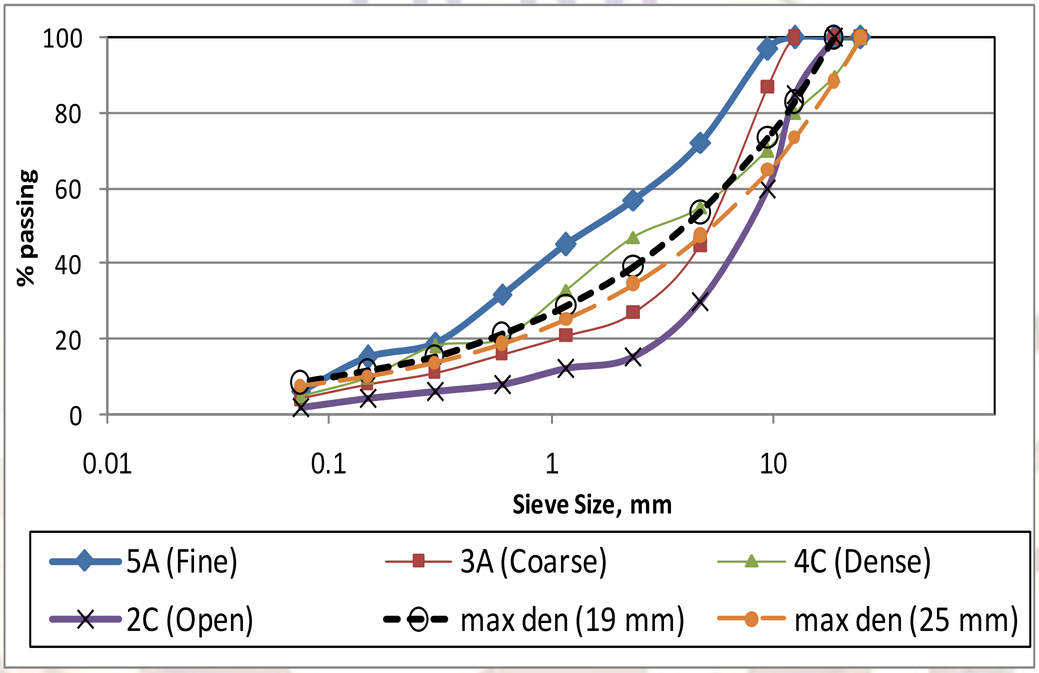
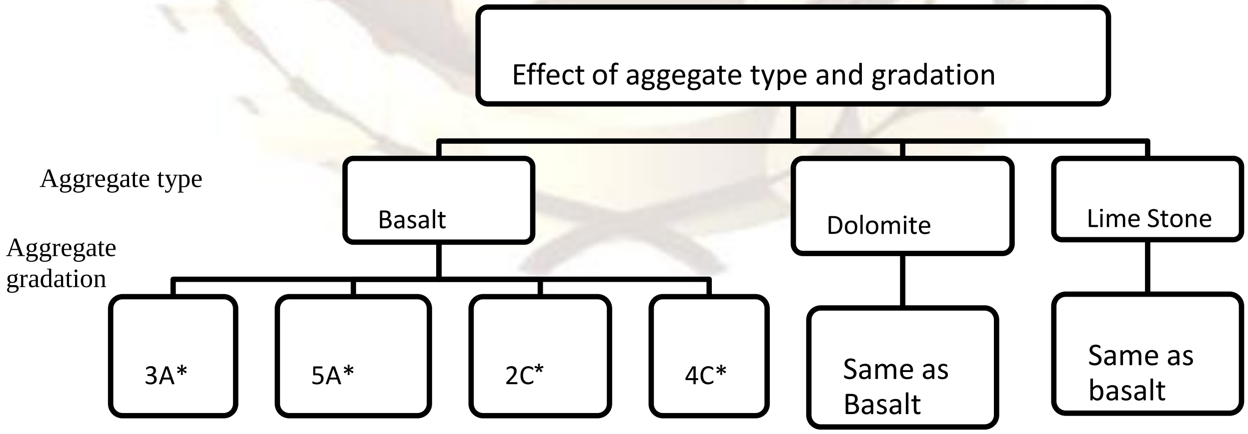



**Figure 1: Aggregate gradation used in the study**




*: Gradation Type according to Egyptian Specification

**Figure 2: Summary of Experimental Design**

## V. Results and Analysis

### Effect of Aggregate Properties on Marshall Test Results

The results of Marshall test are presented in Figure 3. Results indicated that optimum asphalt content (OAC) is different due to aggregate type. The lower OAC was achieved by Basalt mixes ranging from 4.28 to 5.08%. The Dolomite mixes achieved OAC ranging from 4.48 to 5.94%. The highest OAC was achieved by Limestone ranging between (7.74 to 8.75%), as presented in Figure 3(a). This can be explained by the difference in the absorption capacity of each aggregate type. For the same aggregate source, dense gradation consistently had the lowest OAC, this can be explained by the low air available for the asphalt to fill.

Air void (voids in total mix, VTM) at optimum asphalt content was dependent on the gradation but for all mixes it was within the Egyptian specification limits (2 to 6%), as presented in Figure 3 (b). The highest VTM value was for gradation 2C (open graded) for all aggregate types.

All mixes had higher stability than the minimum acceptable value (1200 Ib.) for mixes subjected to medium traffic according to [2]. Mixes subjected to high traffic level should have a minimum stability of 1800 lb. [2]. All mixes presented in this research achieved the Marshall stability of 1800 lb. except Basalt mixes with open or coarse graded 2C and 3A and Dolomite mixes with open gradation 2C.

The highest value of stability was achieved by Limestone aggregate with gradation 4C and the lowest value was achieved by Basalt aggregate of gradation 2C, as presented in Figure 3(c). The main problem with Marshall stability is that some researchers reported that Marshall stability is not related to field performance [19].

Flow values were within the acceptable range (0.08-0.16 in). Basalt mix of gradation 2C had the highest value of flow and Dolomite of gradation 3A had the lowest value, as presented in Figure 3(d).

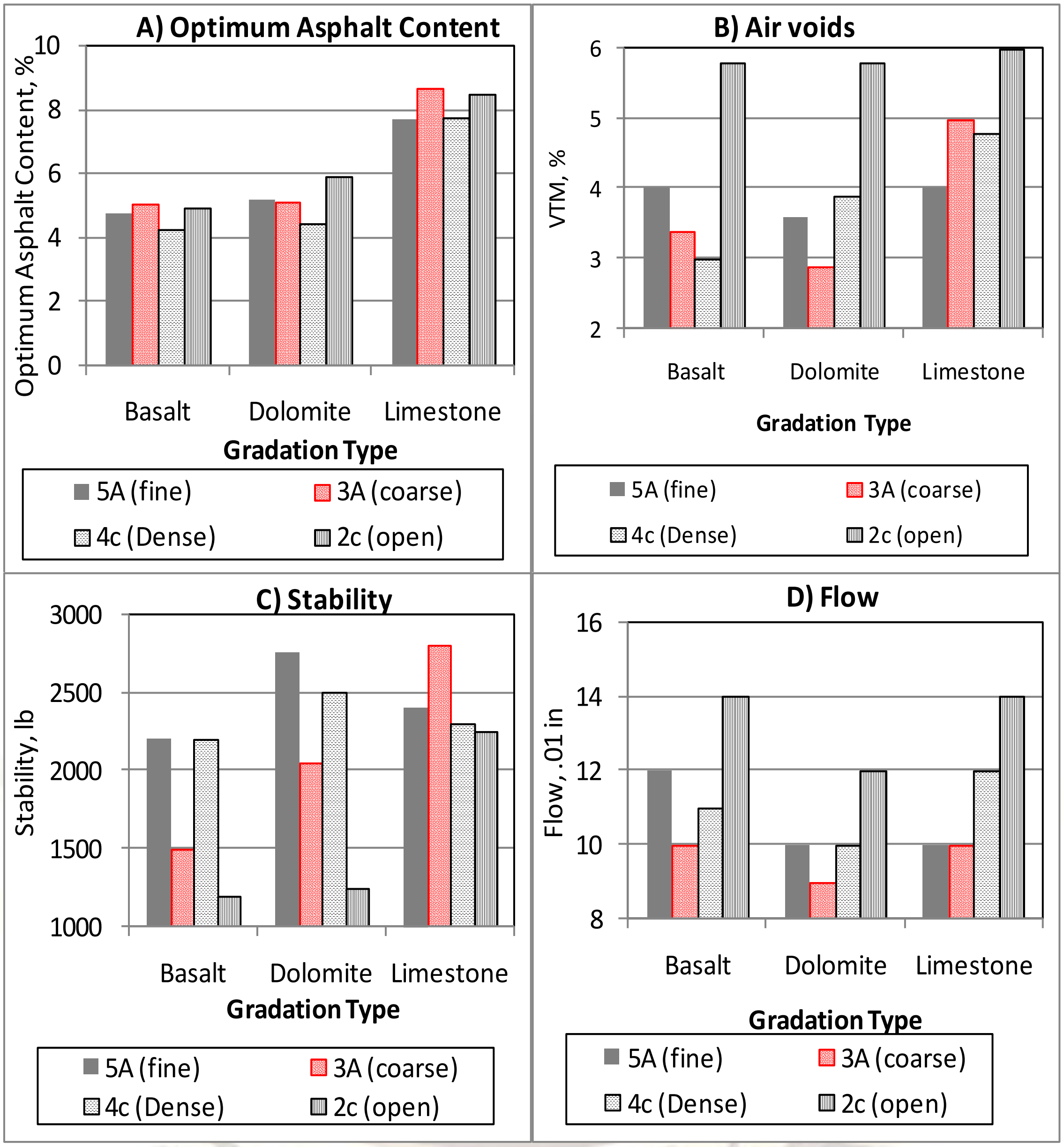



**Figure 3 Effect of aggregate type and gradation on mix properties**

## VI. Effect of Aggregate Properties on Wheel Tracking Test Results

Samples at OAC for all mixes were tested in wheel tracking test (WTT) to study the effects of aggregate types and gradation on the rutting characteristics of asphalt mixes. The results of WTT are presented in Figures (4 and 5). Permanent deformation occurred to WWT spacemen were taken as good indicator for rutting resistance (RR).

*Effect of Aggregate Gradation*:

Figure 4 present the effect of aggregate gradation for each aggregate source used in this study.

Results show that the coarser gradation 3A had the highest RR and the open grade 2C had the lowest RR for all aggregate types. This agrees with the findings of other researchers [10, 20] who recommended the use of continuously coarse graded mix to reduce rutting susceptibility of asphalt concrete. The ranking of the different gradation was dependent on the aggregate source.

For Basalt mixes, gradation 3A had the highest RR followed by 4C, 5A then 2C, as presented in Figure

4(a). For Dolomite the gradation with highest RR was 3A followed by 4C, 5A then 2C, as presented in Figure 4(b). For Lime stone mixes both gradations (3A and 5A) were very similar in their behavior and (2C and 4C) were very similar in their behavior, as presented in Figure 4(c).

***Effects of Aggregate type**:*

Figure 5 presents the effect of aggregate type for each gradation on RR. For all types of gradations, Dolomite mixes had the highest RR, as presented in Figure 5. For fine gradation 5A, the difference between different sources was clear. Basalt source had the lowest RR followed by lime stone then Dolomite, as presented in Figure 5(a).

For both dense graded mixes 4C and coarse graded mixes 3A, no clear difference can be found between Basalt and lime stone mixes, as presented in Figure 5 (b and c). For open graded mixes, no clear difference can be seen between all sources of aggregate, as presented in Figure 5(d). Based on this it can be concluded that the RR is dependent on both aggregate type and aggregate gradation.

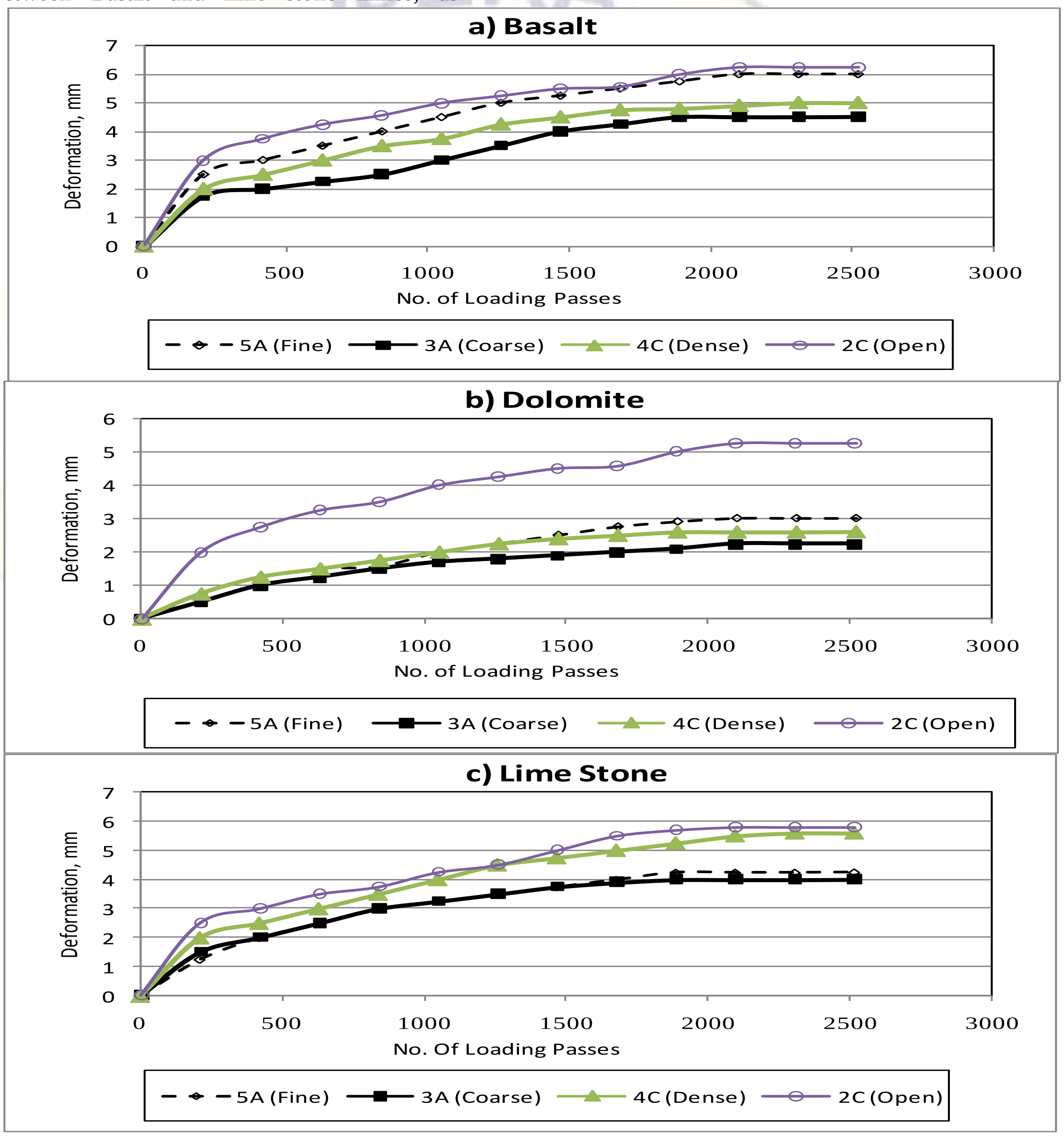



**Figure 4 Effect of aggregate gradation on rutting resistance.**

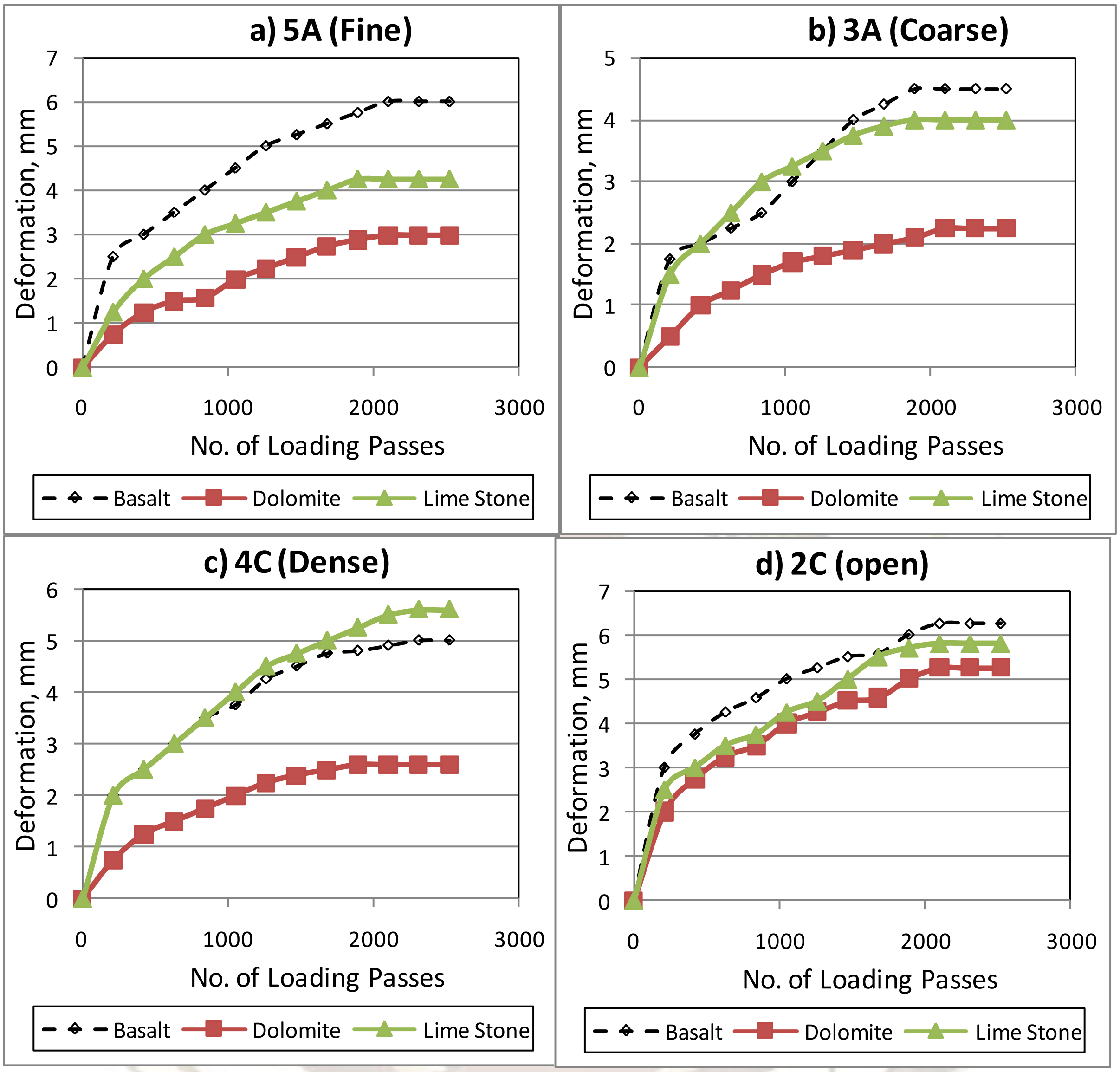



**Figure 5 Effect of Aggregate source on Rutting**

## VII. Relation between mix parameters and rutting

The last stage of the current research was to evaluate the relation between Marshall mix parameters and total rutting resulting from WTT. The results are presented in Figure 6. Figure 6 shows that Marshall flow had the highest linear correlation with rutting, with coefficient of determination ($R^2$) of 0.74, as presented in Figure 6(b). Marshall Stability had the lowest linear correlation with rutting, with $R^2$ of 0.21, as presented in Figure 6(a). The low correlation between rutting and Marshall stability agrees with earlier conclusion in the literature that Marshall stability is not related to pavement performance (19). Increasing air voids caused increase in rutting, however the correlation was poor as $R^2$ was only 0.32, as presented in Figure 6(c). The suitability of using (Marshall stability/Marshall Flow) as a predicator of rutting was evaluated. Results are shown in Figure 6(d), and the relation had $R^2$ of 0.54, which was lower than the $R^2$ found for the relation between Marshall flow and rutting.

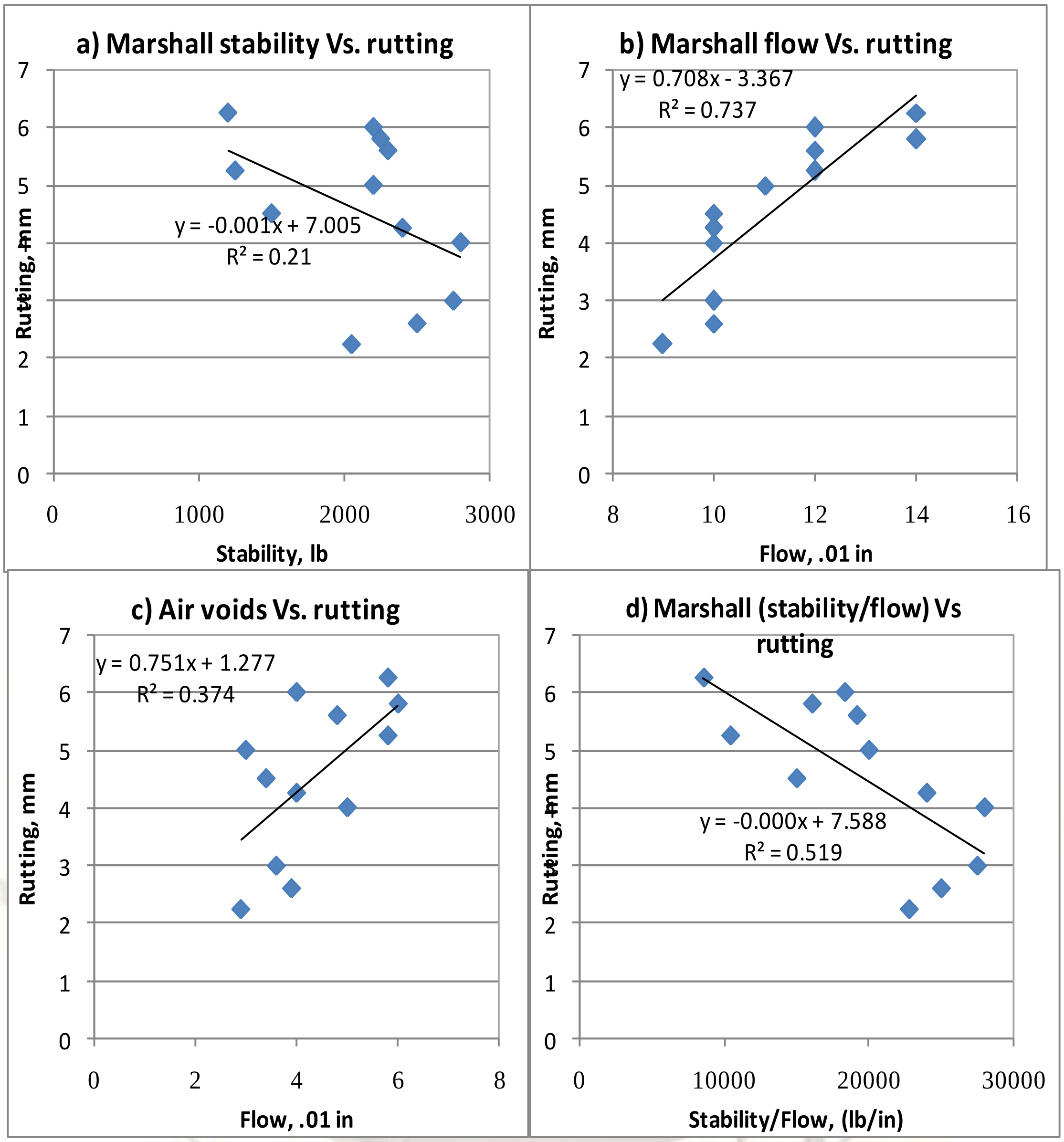



**Figure 6 Relation between Marshall mix parameters and rutting**

## VIII. Summary and Conclusions

Aggregate presents major portion of asphalt concrete and it is responsible for the strength of the mix. The main objectives of this research were to evaluate the impact of aggregate gradation and type on Marshall properties of hot mix asphalt (HMA) and the effect of these properties on the rutting potential of HMA in Egypt and evaluate the relation between mix properties and rutting potential of HMA.

Experimental program was designed and conducted on common asphalt paving mixtures of different aggregate sources and gradations. Samples prepared at optimum asphalt content, as defined by Marshall method, were tested using wheel track test and permanent deformation was measured.

Study results and their analysis showed that all mixes had higher stability than the minimum acceptable value for mixes subjected to medium traffic. However, for heavy traffic, all mixes presented in this research achieved the minimum Marshall stability except Basalt mixes with open or coarse gradations (2C and 3A) and Dolomite mixes with open gradation 2C.

The highest value of stability was achieved by Limestone aggregate with gradation 4C and the lowest value was achieved by Basalt aggregate of gradation 2C. Flow values were within the acceptable range (0.08-0.16 in). Basalt mix of gradation 2C had the highest value of flow and Dolomite of gradation 3A had the lowest value.

Rutting resistance of asphalt paving mixes is affected by the mix gradation and type of aggregate. Coarser gradation 3A had the lowest rutting for all types of aggregate, while open graded mixes 2C had the highest permanent deformation. Dolomite had the lowest rutting for all types of gradations. Dolomite mixes of coarse gradation 3A had the lowest rutting and lowest Marshall flow. Marshall flow had the highest linear correlation with rutting, with coefficient of determination ($R^2$) of 0.74. Marshall Stability had the lowest linear correlation with total rutting with $R^2$ of 0.21.

## References


[1] Prowell, Brian D., Zhang, Jingna and Brown, E. R. (2005). Aggregate Properties and the Performance of Superpave Designed Hot Mix Asphalt. NCHRP Report 539, 2005, http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_539.pdf

[2] Roberts, Freddy. L., Hot Mix Asphalt Materials, Mixture Design and Construction. National Center for Asphalt Technology, Auburn University, Second Edition 1996.

[3] Tashman, L. (2003). Microstructural viscoplastic continuum model for asphalt concrete. Ph.D. Dissertation, Texas A&M university, 2003. Accessed on line March 2008. http://txspace.tamu.edu/bitstream/handle/1969.1/313/etd-tamu-2003C-CVEN-Tashman-1.pdf?sequence=1.

[4] White, T. D., Starkville, J. E., Haddock, A. J. T., Hand, H. F. Contributions of pavement structural layers to rutting of hot mix asphalt pavements. NCHRP Report No. 468, TRB, Washington D.C., 2002. Accessed on line March-2008, http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_468-a.pdf.

[5] Brown, E.R. and Cross, S. A. (1992). A national study of rutting in hot mix asphalt (HMA) pavements. National Center for Asphalt Technology, NCAT Report 92-05, Auburn University. http://www.eng.auburn.edu/files/centers/ncat/reports/1992/rep92-05.pdf.

[6] Gaballa, A.A. (1993). Rutting of Asphalt Pavements in Egyptian Roads and Methods of Its Prediction and Evaluation", Ph.D. Dissertation, Faculty of Engineering, Zagazig University.

[7] El-Hamrawy, S. A. (2000). Rutting Determination in Flexible Pavements (Experimental and Theoritical Study). Proceeding, Mansoura Third International Engineering Conference, Vol. (1) El-Mansoura, Egypt.

[8] Bahgat, A. and Zahw, M. A. (1993). Effect of Chemical and Physical Properties of Asphalt Cements Upon the Rutting Resistance of Asphaltic Concrete Mixes. 1st IRF Spainian Highway Conference, Madrid, pp. 383-391.

[9] Noureldin, A.S., Al-Dhalaan, M.A., Fatani, M.N.Y. and Abdulwahhab, H. (1994). National Study of Rutting of Asphalt Pavements in Saudi Arabia. 6th Conference of Asphalt Pavements, Southern Africa.

[10] El-Basyouny, M.M. and Mamlouk, M.S (1999), Effect of aggregate gradation on rutting potential of Superpave mixes, Paper presented at 78th annual meeting of the Transportation Research Board, Washington D.C.

[11] Garba, Rabira (2002). Permanent Deformation Properties of Asphalt Concrete Mixtures. PhD Dissertation, Department of Road and Railway Engineering, Norwegian University of Science and Tecnology.

[12] Cross, S.A., Adu-Osei, A., and Hainin, M.R. (1999). Effect of gradation on performance of asphalt mixtures. Paper presented at 78 th annual meeting of the Transportation Research Board, Washington D.C.

[13] Carpenter, S.H. and Enockson, L. (1987). Field analysis of rutting in overlays of concrete Interstate pavements, TRR 1136, Transportation Research Board, Washington D.C.

[14] Oliver, J.W.H., Jameson, G.W., Sharp, K.G., Vertessy, N. J., Johnson-Clarke, J. R. and Alderson, A. J. (1997). Evaluation of rut resistant properties of asphalt mixes under field and laboratory conditions. TRR 1590, Transportation Research Board, Washington D.C.

[15] Cross, S.A. and Brown, E.R. (1992). Selection of aggregate properties to minimize rutting of heavy-duty pavements, in Meininger, R.C. (ed), Effect of Aggregate and Mineral Fillers on Asphalt Mixture performance, ASTM, STP 1147.

[16] Quadis, A.S. And Shweily, H.A. (2007). Effect of aggregate properties on asphalt mixtures stripping and creep behavior. Construction and Building Materials, vol. 21, pp. 1886-1898.

[17] Egyptian Standard Specification for Highways, General Authority for Roads, Bridges and Land Transportations (GARBLT), Egypt, 2001.

[18] Cooley, L. Allen, Kandhal, Prithvi S., Buchanan, M. S., Fee, Frank and Epps, Amy (2000). Loaded Wheel Tester in the United States: Sstate of Practice. NCAT Report 00-04, 2000. http://www.eng.auburn.edu/files/centers/ncat/reports/2000/rep00-04.pdf.

[19] Roberts, Freddy L., Mohammad, Louay N., and L. B. Wang (2002). History of Hot Mix Asphalt Mixture Design in the United States. Journal of Materials in Civil Engineering, ASCE, Vol. 14, No. 4,, pp. 279-293.

[20] Epps, Amy L., Hand, Adam J., Epps, Jon A., and Sebally, Peter E. (2001). Aggregate Contribution to Performance of Hot Mix Asphalt at WesTrack. ASTM, STP 1412, 2001, pp 30-43. Edited by Thomas D. White, Sam R. Johnson, John J. Yzena.