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COMPARISON BETWEEN MARSHALL AND SUPERPAVE MIXTURES DESIGN

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ABSTRACT

Roads in Iraq are performing poorly with pavement life much shorter than the expected. The high traffic intensity in terms of commercial vehicles, the serious overloading of trucks and significant variation in daily and seasonal temperature of the pavement have been responsible for early development of distress like rutting, fatigue and thermal cracking on bituminous surfacing. One of the advantages of the Marshall Mix Design method is that the performance of the mixes can be expected for local materials and environmental impact.

The Superpave mix design method differs from the Marshall Mix design methods by using performance-based and performance-related criteria to design the proper asphalt mix. This allows a direct relationship to be drawn between the lab and field performance of the asphalt mix.

This technology has a tremendous potential to be implemented in Iraq, which will pay itself with higher performance and longer lasting roads. Hence, there is need to have a comprehensive study comparing the design of bituminous mixes using both Superpave and the Marshall method of Mix Design.

The main objective of the study is the comparison between traditional Marshall Design method and the Superpave system design method in the wearing course mixes in flexible pavements. This process will be carried out by evaluating the volumetric, mechanical properties and moisture susceptibility.

المقارنة بين طريقة مارشال والتصميم الفائق في تصميم الخلطات

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الموجز

الطرق في العراق انجزت على نحو ضعيف مع عمر التبليط الى حد معين اقل من المتوقـــع. ان شدة المرور العالي بالنسبة الى المركبات التجارية ،سلسلة الشاحنات ذات الحمولـــة العاليـــة والاخـــتلاف الملحوظ في درجات الحرارة اليومية والفصلية للتبليط هي المسوولة عن الاجهـــادات مثـــل التخـــد والكلـــل والتشققات الحرارية على السطح القيري.واحد من اهم الفوائد لطريقة مارشال لتصميم الخلطات الاسفلتية انـــه يمكن التوقع بأداء الخلطة للمواد المحلية والتأثيرات البيئية.

ان طريقة نظام التبليط الفائق يختلف عن طريقة تصميم مارشـــال باســـتخدام اســـاس الادء وربط الاداء بمعايير.وهذا بدوره يساعد على ايجاد علاقة مباشرة بين الاداء الحقلي والمختبري في الخلطـــات الاسفلتية.

هذه التقنية لها امكانية كبيرة لتطبيقها في الطرق،التي ثمن نفسها بالاداء الاعلى والطرق التي تدوم اطول. لذالك،هناك حاجة لدراسة شاملة لمقارنة تصميم الخلطات القيرية باســـتخدام طريقتـــي مارشـــال ونظام التبليط الفائق.

الهدف الرئيسي من الدراسة هو المقارنة بين طريقة تصميم مارشال التقليدية وطريقة تصميم التبلـــيط الفائق في طبقة التبليط السطحية للتبليط المرن.هذه العملية سوف تنفذ بتقييم الخواص الحجمية و الميكانيكيـــة والتأثر بالرطوبة.

KEY WORDS: Super pave Mixes, Marshall Mixes, Optimum Asphalt Content, Superpave Gyratory Compactor, Marshall Test.

NOMENELATURE

$B_\circ$ = Optimum Content.

B_1 = % of asphalt content at maximum specific gravity.

B_2 = % of asphalt content at maximum stability.

B_3 =% of asphalt content at 4 % of air voids in total mix.

A.C = Asphalt Content
ASTM = American Society for Testing and Materials.
V.F.A = Voids Filled with Asphalt (%)
V.M.A = Voids in the Mineral Aggregate (% of bulk volume)
A.V = Air Voids in Total Mix.
ESAL =Equivalent Single Axle Load
HMA = Hot Mix Asphalt
ISGC =Iraqi Superpave Gyratory Compactor
OAC =Optimum Asphalt Content
SCRB =State Commission of Roads and Bridges.
SHRP = Strategic Highway Research Program.

INTRODUCTION

Virginia has used the Marshall method of asphalt mix design for many years. The method subjects an asphalt-aggregate mixture to a specified comp active effort supplied by a dropping mass and uses the void structure of the compacted specimen to determine the proper asphalt content. The method has served users of asphalt hot mix well for several decades, but problems have developed recently because of increased traffic loads. As traffic becomes heavier, the Marshall method may not duplicate the kneading action of traffic, and achieving the ultimate purpose, the prediction of mix voids after considerable traffic, becomes more difficult (**Maupin,1998**)..

The Superpave mix design method differs from the Marshall and Hveem mix design methods by using performance-based and performance-related criteria to design the proper asphalt mix. This allows a direct relationship to be drawn between the lab and field performance of the asphalt mix [**Asphalt Institute (1996)**].

COMPARISON BETWEEN MARSHALL AND SUPERPAVE MIXTURES DESIGN

Superpave technology as a new design methodology can be rigorously used under varying traffic and environmental conditions. Although Superpave is recognized as a significant system in the evaluation of asphalt concrete mixes, Iraqi agencies continue to use Marshall Method as a unique mix design method in road projects. Accordingly, an investigation is needed to compare analyze and investigate the performance and the properties of Superpave and Marshall Mix Design methods. There is international concern and interest in implementing Superpave in roads and airport projects to investigate its impact on economic and performance of these projects

Superpave mix design is based on (1) properties of the asphalt binder and aggregate and (2) volumetric properties of hot mix asphalt (HMA). The characteristics of the densification curve obtained during Gyratory compaction of (HMA) are believed to be related to the strength of the aggregate skeleton [**Anderson et al. (2002)**]. The strength of the aggregate skeleton can give an indication of asphalt mixture strength and, consequently, the expected pavement performance. As such many asphalt technologists believe that Superpave Gyratory compactor data can be used to evaluate asphalt mixture strength properties.

The Superpave technology was developed in the United States with proven success. Superpave mixes have been widely used by developed countries over the last few years. Superpave technology is replacing the Marshall method, which was used for asphalt concrete mixture design for almost half a century. The Marshall method was based mostly on experience and statistical analysis. The flexible pavement sections designed using the Marshall method have had mixed success due to poor understanding of mechanism of failure. The partial success has been mainly due to very thick and uneconomical sections. The roads in Iraq are in a highly distressed condition with pavement life much shorter than the expected. A new design methodology, that is more thorough and comprehensive, is required. Superpave technology can be rigorously tested under varying traffic and environmental conditions.

MARSHALL MIX DESIGN METHOD

Bruce Marshall, formerly the Bituminous Engineer with the Mississippi State Highway Department, developed the original concept of the Marshall Method of designing asphalt pavements. The present form of Marshall Mix design method originated from an investigation started by the U.S Army Corps of Engineers in 1943. The purpose of Marshall method is to determine the optimum asphalt content for a particular blend of aggregates and traffic level .The optimum asphalt content is determined by the ability of a mix to satisfy stability ,flow ,and volumetric properties,(**Vasavi K. , 2002**).

Five separated smooth plots with percent of the binder content on x- axis and the following on y-axis

- Unit weight
- Marshall Stability
- Flow
- VMA
- Voids in total mix (Va)

Optimum asphalt content is selected as the average content for maximum specific gravity, maximum stability, and 4% of air voids in the total mix as shown in Equation (1) [**Garber (1993)**] .Thus,

$$B_\circ = \frac{B_1 + B_2 + B_3}{3} \qquad (1)$$

where:-

$B_\circ$ = optimum content.

B_1 = % of asphalt content at maximum specific gravity.

B_2 = % of asphalt content at maximum stability.

B_3 =% of asphalt content at 4 % of air voids in total mix.

SUPERPAVE MIX DESIGN METHOD

To predict how well an asphalt mix will perform at a project site, mix designers need to be able to simulate in the laboratory the effects of traffic, climate, and construction practice in the field. To do this, the Superpave system uses a new, quiet, and easy-to-use method of laboratory compaction the Superpave Gyratory Compactor, developed by the Strategic Highway Research Program (SHRP).

Khaled and Jason [1998] stated that the optimum asphalt content was determined by compacting and analyzing two specimens at each of the following four asphalt binder contents:

- Estimated asphalt binder content (obtained previously from the trial blends),
- Estimated asphalt binder content + 0.5%,
- Estimated asphalt binder content - 0.5%, and
- Estimated asphalt binder content + 1.0%

Compaction and volumetric properties are evaluated for the selected blend at the different asphalt binder contents. From these values, graphs of air voids, VMA, and VFA are plotted as a function of asphalt content. The design asphalt binder content is established at 4.0 percent air voids, and the other mixture properties are checked.

SUPERPAVE GYRATORY COMPACTOR

In order to use Superpave system in the comparison process in asphalt concrete mixture, a Locally Superpave Gyratory Compactor has been manufactured to assist in the preparation of the required Superpave specimens

The Gyratory Compactor is an integral part of the mix design and testing phases of Superpave .The Gyratory Compactor compacts an asphalt specimen by applying a pressure of 600 KPa to the mix while gyration the mould at an angle 1.25o. The height of the specimen is continually monitored, providing the information on density of the mix throughout the compaction cycle. This information is recorded and can be sent to computer, printed, or plotted [**Traxler Electronic Laboratory Inc. (2001)**]. **Figure 1** Shows Iraqi Superpave Gyratory Compactor which is manufactured by Abbas F. Jassim, M.Sc student/ Highway and Transportation Engineering in 2005[**Abbas ((2005)**].

MATERIALS USED IN THE STUDY

Materials used in this study are locally available .They are included aggregate, mineral filler, and asphalt cement.

Asphalt Cement

One penetration grade (40-50) of asphalt cement is used from Daurah refinery .The physical properties and tests of asphalt cement are presented in **Table 1**.

Aggregates

The (crushed) aggregate used in this work is brought from the hot mix plants of Ammanat Baghdad at (AL-Tagi). The source of the two aggregates is from Al- Nibaee quarry.

To produce the identical and controlled gradation, aggregates are sieved and recombined in the laboratory to prepare the selected gradation, as shown in **Figure 2** Within the specifications requirement of ASTM [D-3515] for (12.5mm) nominal size.

The mid of SCRB specifications is followed to select the suitable gradation of the original mix. The gradation is presented in **Table 2** and described as type III in SCRB (2004).In Iraq, this gradation is well recommended by SCRB and Ammanat Baghdad to be used for the purpose of wearing course HMA preparation. Compared with the Superpave classification, the gradation represents ARZ which is used to prepare the original mix in this study.

Mineral Filler

Ordinary Portland cement (from Badoush factory) has been used in this study. The chemical composition and physical properties are shown in **Table 3**.

EXPERIMENTAL WORK

The main asphalt concrete mixture properties (Stability, unit weight, flow, volumetric properties, stiffness, and permanent deformation) are obtained by performing the required laboratory tests.

Marshall Specimen

Specimen Preparation and Compaction (Marshall Specimen)

The aggregate is first dried to constant weight at 110 °C, separated into desired size and recombined with mineral filler in order to meet the required gradation for each specimen .The aggregates are heated to a temperature of 175 to 190 °C [**Kuwait Motorway specification (1998)**], the compaction moulds assembly and hammer are cleaned and kept pre-heating to a temperature of 100 to 145 °C. The asphalt is heated to temperature of 121 to 138 °C and the requirement amount of first trail of asphalt is added to the heated aggregate and thoroughly mixed.

The mix is placed in a mould and compacted with standard number of blows (75) as specified. The samples are taken out of the mould after few minutes using sample extractor.

Determining the Marshall Stability and Flow of Each Specimen (Marshall Specimen)

The Marshall Stability and flow test are performed on each specimen, which is tested for bulk specific gravity, in accordance with procedure described by ASTM [D1559] for "resistance to plastic flow of bituminous mixtures" using Marshall Apparatus.

In conducting the stability test, the specimen is immersed in bath water at temperature 60 ± 1°Cfor a period of 30 minuets .It is then placed in the Marshall Stability testing machine and loaded at a constant deformation of 5 mm per minute until failure. The total maximum in KN (that causes failure of specimen) is taken as Marshall Stability. The stability value so obtained is corrected for volume .The total amount of deformation is units of 0.25 mm that occur at maximum load recorded as Flow Value .The total time between removing the specimen from the bath and the completion of the test should not exceed 30 seconds. In order to calculate the Marshall volumetric properties, many procedures and Equations are used in determining these properties.

Superpave Specimen

Preparation of HMA Mixtures

Once the aggregate blend is selected and the initial trial asphalt binder content is calculated, the HMA mixtures are prepared [**FHWA (2004)**]. This phase consists of the following main steps:

- Heating the aggregates and asphalt binder to the mixing temperature (159 ± 3ºC).
- Mixing both components and short-term age mixture for 4 hours at 135°C.
- Compaction of the mixture at a temperature of 145 ± 3°C.

Compaction

All specimens are compacted using the Superpave Gyratory Compactor (SGC).

In Superpave, as with other mixture design procedures, asphalt mixtures are designed using a specific compactive effort. Compactive effort is a function of the design number of gyrations, N_{des} . N_{des} is used to vary the compactive effort of the design mixture as a function of climate and traffic level. Two other compaction levels are of interest: the initial number of gyrations (N_{ini}) and maximum number of gyrations (N_{max}) [**FHWA (2004), and Yildirim et al. (2000)**].

$$\text{Log } N_{ini} = 0.45 \times \text{Log } N_{des} \qquad (2)$$

$$\text{Log } N_{max} = 1.10 \times \text{Log } N_{des} \qquad (3)$$

Climate is represented by the average design for high air temperature. For Baghdad, Iraq, it is >44 ºC. Selected traffic levels are 10-30 million ESALs for crushed gravel. For the selected traffic levels, N_{ini} , N_{des} and N_{max} are 9, 135, and 220 respectively. Specimens for the volumetric analysis are compacted to N_{max} .

OPTIMUM ASPHALT CONTENT CALCULATION

To calculate the optimum asphalt content, Marshall and Superpave mix designs are followed as stated in the following articles.

Marshall Mix Design

The results of Marshall Tests show almost typical relationships between Marshall Properties and asphalt content. **Figure 3** Shows the above mentioned relationships for different mixtures. Five different percentages (4.0, 4.5, 5.0, 5.5, and 6.0) % of Daurah (40-50) asphalt cement are used with ordinary Portland cement (filler), and (12.5) mm nominal aggregate size is used for dense mix in accordance with SCRB specification (R9), for wearing course [**SCRB (2003)**]..

The [**SCRB (2003)**] specification of mix design criteria for heavy traffic roads recommends the following values for surface course, as shown in **Table 4**:

The Optimum Asphalt Content (O.A.C) of the various mixes is determined from the following Marshall Curves; (Stability, Bulk density, and 4% of air voids) .As previously mentioned in chapter three, the Optimum Asphalt Content of the origin mix is determined to be 4.7 %.

Superpave Mix Design

The aggregate and asphalt cement used for the Superpave level one mix design are the same materials as those used in the Marshall Mix design. A (0.45) power gradation chart containing each trial blend is displayed in **Figure 2**, which includes the Superpave mix design criteria. The criteria are determined depending on a (12.5 mm) nominal aggregate size.

Climate is represented by the average design for high air temperature. For Baghdad, Iraq, it is >44 ºC. Selected traffic levels are 10-30 million ESALs for crushed gravel. For the selected traffic levels, N_{ini} , N_{des} and N_{max} are 9, 135, and 220 respectively. Specimens for the volumetric analysis are compacted to N_{max} .

The estimated volumetric properties of the samples and the criteria used to select the appropriate aggregate blend are also listed in **Table 5**. These criteria are also determined by considering 10-30 million design ESALs.

The estimated volumetric properties found in **Table 5** for the asphalt mix containing aggregate blend A.R.Z at 4.0 percent air voids is used to estimate the optimum asphalt content. This value is determined to be 4.3 percent. To determine the corrected optimum asphalt content, four samples are made at the estimated optimum asphalt content, 3.8 percent, 4.8 percent, and 5.3 percent, asphalt contents. For the samples, the G_{mm} and the average percent of G_{mm} at $N_{int.}$ and $N_{max.}$ are shown in **Table 6**. The volumetric properties of the compacted specimens used to determine the optimum asphalt content are shown in **Table 5-4**. Plots showing the properties versus percent asphalt content, at an $N_{des.}$ of 135 gyrations, are shown in **Figure 4**. Based on the volumetric analysis, the optimum asphalt content is established at 4.0 percent air voids and is determined to be 4.6 percent. The other volumetric properties are checked to determine if the Superpave criteria are met. The estimated properties of the asphalt mix at 4.6 percent asphalt content and the criteria are shown in **Table 6**. As before, the criteria are based on a design in which ESALs is 10-30 million. The optimum asphalt content of 4.6 percent passes all of the criteria in the Superpave manual.

CONCLUSIONS AND RECOMMENDATIONS

1- The estimated asphalt content for the Superpave mix design is found to be lower than that if Marshall Mix Design method is used .This indicates that the Superpave mix design is more economical.

2- Role of modified asphalt to improve the asphalt-concrete mixture against rutting by using a trial field section.

REFERANCES

Anderson, R.M., Turner, P.A., Peterson, R.L., Mallick, R.B. (2002), "Relationship of Superpave Gyratory Compaction Properties to HMA Rutting Behavior", National Cooperative Highway Research Program Report 478, National Academy of Sciences, Washington, DC.
URL: http://gulliver.trb.org/publications/nchrp/nchrp_rpt_478.pdf

Asphalt Institute, (1996),"Mix Design Methods for Asphalt Concrete and other Hot Mix type," Manual Serial No.2, sixth Edition, Lexington, KY.

ASTM, (1989)," American Society for Testing and Materials Annual Book of ASTM Standards", Section 4, Vol, (04-03).

FHWA (2004),"V-Superpave Mixture Design Guide"
URL: http://www.nhi.fhwa.dot.gov./download/material/131053/RM/RML05.pdf

Garba,R.,(2000),"Permanent deformation Properties of asphalt Mixture ," Norwegian university of science and technology ,department of civil and transportation engineering,(NVF) conference .
Khaled, K.,and Jason ,S.,(1998),"A Prelemnary Evaluation of Superpave Level One Mix Design Procedure ," Department of civil and architectural Engineering ,University of Wyoming .

Maupin, G.W. (1998) "Compression of Several Asphalt Design Methods ", Virginia Transportation Research Council.

SCRB (State Commission of Roads and Bridges), (2003) “Hot Mix Asphalt Concrete Pavements Section R9”, Revision of Standard Specifications for Roads and Bridges, Ministry of Housing and Construction, Department of Planning and Studies.

Troxler Electronic Laboratory, Inc., (2001)" Specimen preparation in superpave mix design,"
URL: www.traxlerlab.com

Yildirim, Y., Solaimanian, M., McGennis, R. B.,and Kennedy,T.W.,(2000), “Comparative Analysis of Volumetric Properties for Superpave Gyratory Compactors.” In Transportation Research Record 1712, TRB, National Research Council, Washington, DC.

Table 1 Physical Properties of Asphalt Cement

Tests	Units	Penetration grade (40-50)
Penetration (25°C,100 gm,5 sec) ASTM D-5	1/10 mm	49
Absolute viscosity at 60° C ASTM D-2171(*)	Poise	2065
Kinematics viscosity at 60° C ASTM D-2170(*)	cSt	430
Ductility (25°C ,5 cm /min)ASTM D-113	cm	>100
Softening point (ring and ball)ASTM D-36	°C	48
Specific gravity at 25° C ASTM D-70)(*)	…..	1.034
Flash point ASTM D-92 (Cleveland open –cup)	°C	330
After thin film test		
Penetration (25°C,100 gm,5 sec) ASTM D-5	1/10 mm	25
Ductility (25°C ,5 cm /min |)ASTM D-113	cm	>100
Loss in weight (163° C,5 hr)	%	0.12

(*)=The test was conducted in Daurah refinery

Table 2 Aggregate Selection as Original Selection

No.	Sieve opening (mm)	Sieve size	Specification range (%)*	Selected gradation (%)
1	19	3/4	100	100
2	12.5	1/2	100-90	95
3	9.5	3/8	76-90	83
4	4.75	No.4	44-74	59
5	2.36	No.8	28-58	43
6	1.18	No.16	…..	32
7	0.6	No.30	…..	25
8	0.3	No.50	5-21	16
9	0.15	No.100	…..	10
10	0.075	No.200	4-10	5

* [SCRB 2004]

Table 3 Chemical Composition and Physical Properties of Mineral Filler

Chemical composition	Portland cement *
Lime (CaO)	62.2
Sulfuric anhydride (SO3)	1.5
Magnesia (MgO)	3.7
Ferric oxide (Fe2O3)	5.3
Alumina(AL2O3)	4.4
K2O	0.58
Na2O	
Loss on ignition (L.O.I)	0.3
I.R	0.48
Ca(OH)2	……
SiO2	21.54
SiO3	……
TOTAL	100
Apparent specific gravity	3.13
%passing sieve no.200	95

*= These tests from the factories

Table 4 SCRB Specification of Mix Design

Properties	*S.C.R.B specification Limits*
Marshall stability, KN	8 minimum
Marshall flow, mm	2 – 4
Air voids, %	3- 5
Voids filled with Asphalt , %	65 – 85
Voids in mineral aggregate, %	14 minimum

Table 5 Estimated Volumetric Properties for the Asphalt Mix

Estimated mixtures volumetric properties @N $_{des}$					Estimated mixtures density properties	
Trail A.C %	Estimated A.C %	% air voids	% VMA	% VFA	Gmm @N=9	Gmm @N=220
4.0	4.3	4.0	14.0	71.4	83.55	96.3
Criteria		4.0	14.0	65-75	Less than 89%	Less than 98%

Table 6 G_{mm} and Percent G_{mm} for Trial Mixes at $N_{int.}$, $N_{des.}$, and $N_{max.}$.

Percent AC	Max. Specific Gravity (G_{mm})	Percent G_{mm}	
		$N_{int.}$	$N_{max.}$
3.8	2.49	83.0	96.1
4.3	2.472	84.6	97.5
4.8	2.454	85.0	97.7
5.3	2.436	84.5	98.9

Figure 1 Iraqi Superpave Gyratory Compactor.

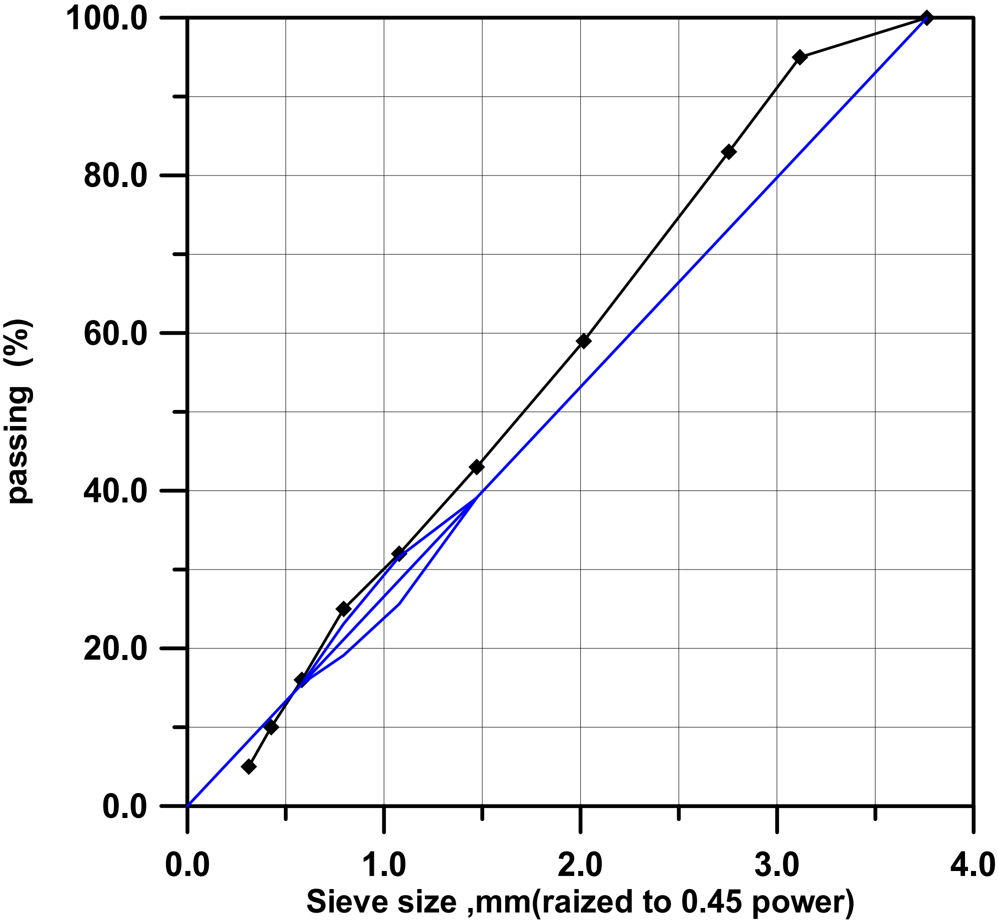

Figure 2 Gradation of Selected Aggregate

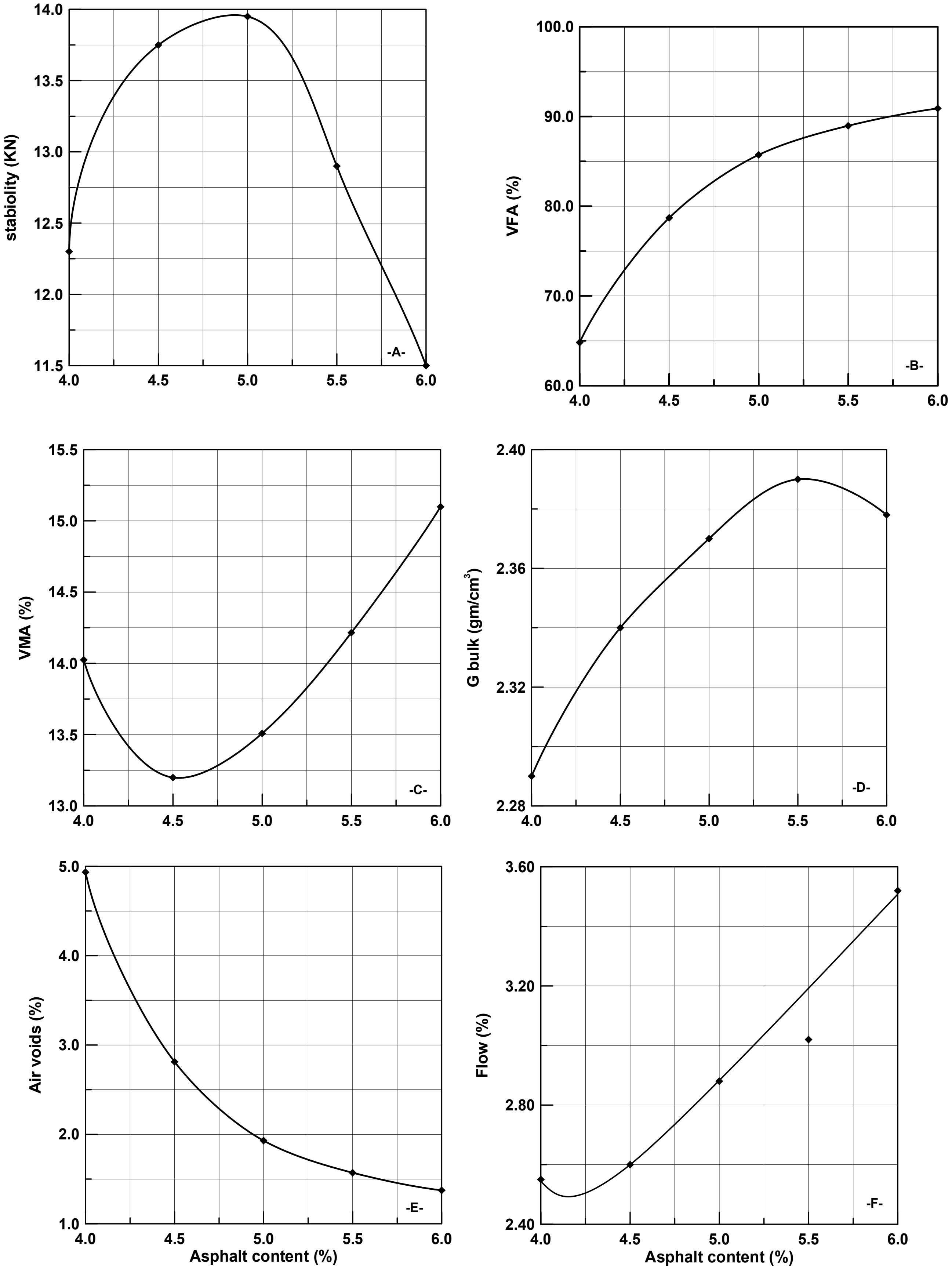

Figure 3 Marshall Mix Design Plots

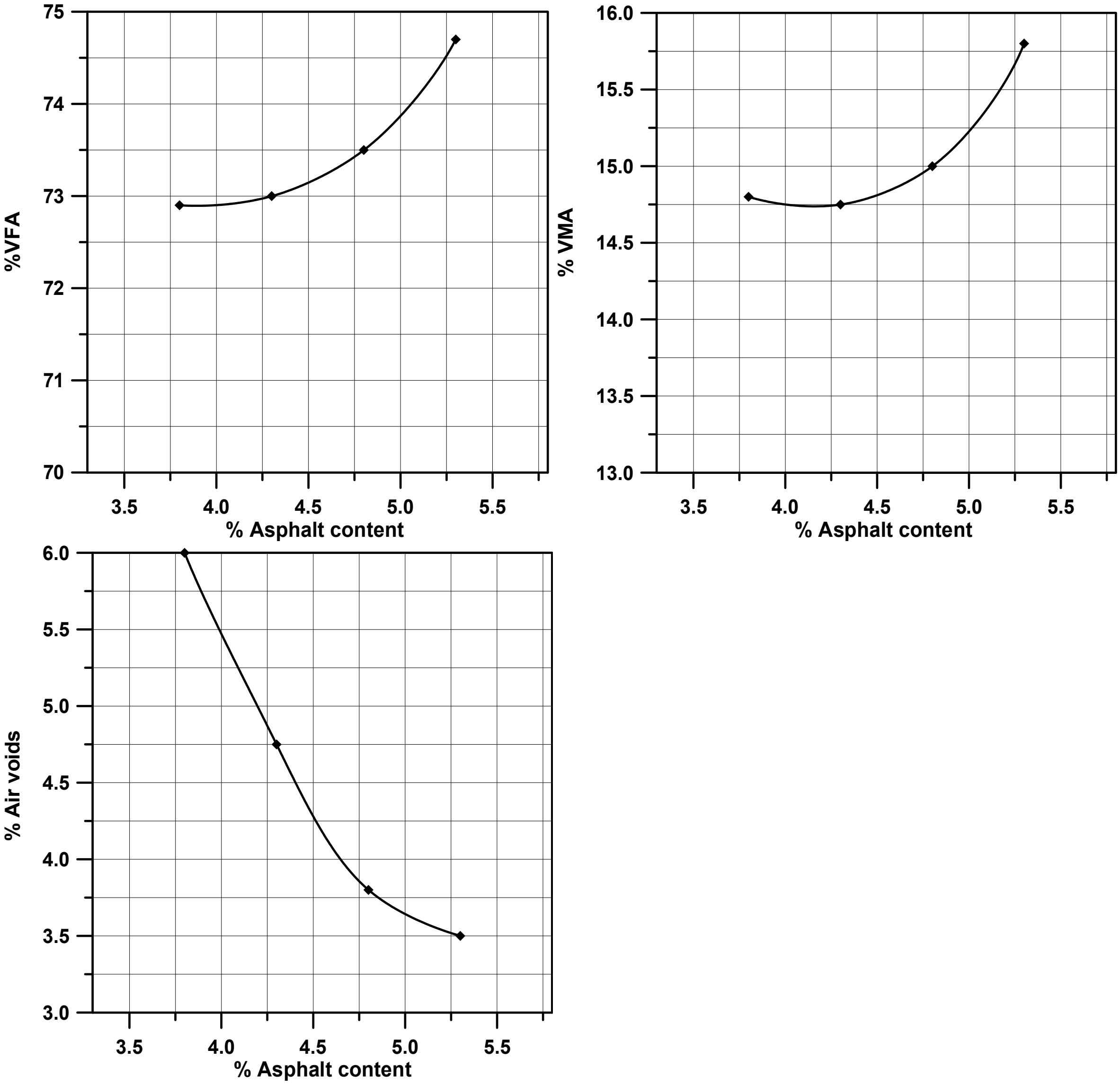

Figure 4 Volumetric Properties versus Asphalt Content for Superpave Level One Mix Design.