Journal of Engineering and Development, Vol. 13, No. 2, June (2009) ISSN 1813-7822

Comparative Evaluation For Mix Design of Marshall and Superpave Methods

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Abstract

The SHRP conducted a $ 50 million research effort to develop a Superpave mix design as a new concept for the design of bituminous mixes. The main objective of the present research is the comparison between the design of Marshall and Superpave mixes, if applied in mix design of the wearing course layer in flexible pavements. A detailed experimental work is carried out to achieve the objectives of the study by preparing asphalt concrete Marshall and Superpave specimens to evaluate the volumetric properties for each mix design method. These specimens were tested by Lottman test to evaluate the tensile strength value. The effect of additives and film thickness of asphalt on the performance of these mixes was also investigated. To compare between two mix design methods, Marshall test was also investigated. From the analysis results, it is concluded that; Superpave Gyratory compactor is capable of achieving air void contents much lower than that when using Marshall hammer. it is also concluded that; the Superpave mixes are more economical as compared with traditional Marshall mixes. In addition, adding carbon fiber and lime to the mixes increases the tensile strength value.

الخلاصـــــة

أنفق برنامج بحوث الطرق الاستراتيجية الأمريكي(SHRP) خمسين مليون دولار كجهد بحثي من اجل تطوير مفهوم جديد لتصميم الخلطات الإسفلتية. إن الهدف الرئيسي من البحث الحالي هو عمل مقارنه بين طريقة تصميم خلطات مارشال التقليدية و خلطات التبليط الفائق لطبقه الاكساء السطحية في طرق التبليط المرنة. ولقد تم استخدام العمل المختبري بشكل مفصل لإنجاز أهداف الدر اسه و ذلك بتحضير عينات من مارشال والتبليط الفائق من أجل تقييم الخواص الحجمية لكل طريقة تصميم. وتم فحص هذه العينات بفحص لوتمان من اجل تقييم قيمة تحمل الشد لهذه الخلطات. وكذلك تم الأخذ بنظر الاعتبار تأثير نوع المضافات وسمك الإسفلت على أداء هذه الخلطات. ومن أجل عمل مقارنة بين طرق تصميم الخلطة فلقد تم عمل فحص مارشال لكلا الخلطتين. ومن نتائج التحليل تم الاستنتاج بان: جهاز التبليط الفائق له قدرة أفضل على أنتاج خلطات ذات فجوات هوائية اقل فيما لو استخدمت مطرقة مارشال. ولقد أستنتج أيضا بأن خلطات التبليط الفائق اكثر اقتصادية بالمقارنة مع خلطات مارشال التقليدية. بالإضافة إلى ذلك، فان إضافة ألياف الكربون والنورة إلى هذة الخلطات سيؤدي إلى زيادة قيمة تحمل قوة الشد.

Keywords:- Marshall Mixes, Superpave Mixes, Moisture Damage, Asphalt Film Thickness, Carbon Fiber.

1.Background

Most of the hot mix asphalt (HMA) produced during the 50 years between the 1940 and mid 1990 were designed using the Marshall methods, and the increase in traffic volumes and heavier loads became initiative for the Strategic Highway Research Program (SHRP) in 1988. After five years of efforts, a new mix design, Superior Performing Asphalt Pavements (Superpave), was developed. Superpave takes into consideration the factors responsible for the typical distress on asphalt pavements, rutting, fatigue, and thermal cracking. With the introduction of Superpave Mix Design, the Marshall method of Mix design has become obsolete in highway pavement, (*Vasavi*, 2002).

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.

2.Problem Statement

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.

Superpave technology as a new design methodology can be rigorously used under varying traffic and environmental conditions, in spit of it is not used internationally , it is still under experiment, and only adopted in few united state. 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 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.

3. Objectives of the Study

The main objective of the study is the comparison between the properties of Marshall and Superpave mixes for wearing course mixes in flexible pavements. This process will be carried out by evaluating the volumetric properties, and the resistance to moisture damage in flexible pavements and Marshall test will be examined for these two types of mixes .

4. Material Properties

Materials

The Materials used in this study are locally available and selected from the currently used materials in road construction in Iraq.

Asphalt Cement

One type of asphalt cement (40-50) penetration graded was used in this study, is obtained from Dourah refinery. The physical properties of this type of asphalt cement are shown in Table (1).

Table (1): Physical Properties of Asphalt Cement.

Test	Unit	ASTM	Results D (40-50)
Penetration 25°C,100 gm , 5 sec.	1/10 mm	D5	42
Absolute Viscosity at 60°C (*)	Poise	D2171	2070
Kinematics' Viscosity at 135°C (*)	C St.	D2170	370
Ductility (25°C, 5 cm/min.)	Cm.	D 113	>100
Softening Point (Ring & Ball)	C°	D 36	51.0
Specific Gravity at 25°C (*)	…….	D 70	1.04
Flash Point	C°	D 92	332

(*) The test was conducted in Dourah refinery

Aggregate

One type of crushed aggregate was used in this study, which was brought from Amanat Baghdad. The source of this type of aggregate is Al-Taji quarry. The physical properties of the aggregate are shown in Table (2), and the aggregate gradation was the same gradation that used in the construction of the expressway No.1.

One nominal maximum size (12.5) was selected with two aggregate gradations (R1 and R9), where R1 represent the part one of the expressway No.1 and R9 represent the part nine of the same project. The gradation R9 is passing through the Superpave limitation control points and restricted zone, while, the gradation R1 is located out of the Superpave restricted zone requirement. These two gradations were selected to compare the effect of restricted zone on the mix performance. Mixes design were prepared for heavy traffic level using the Superpave methodology and the traditional Marshall methodology. These gradations are shown in Figure (1) and presented in Table (6).

Table (2): Physical Properties of Al-Taji Quarry Aggregate.

Property	Coarse Aggregate	Fine Aggregate

	R1	R9	R1	R9
Bulk specific gravity ASTM C 128	2.518	2.5189	2.615	2.6225
Apparent specific gravity ASTM C127 and C128	2.553	2.554	2.662	2.689
Percent water absorption ASTM C 127 and C 128	0.556	0.56	0.68	0.94

Mineral Filler

One type of mineral filler (Ordinary Portland Cement) has been used in this study, which is obtained from Badoush factory. The physical properties are shown in Table (3).

Table (3): Physical Properties of Filler (Cement).

Property	Results
Specific Gravity	3.12
% Passing sieve No.200 ASTM C117	95

Additives

Two types of additives (carbon fiber and lime) have been used in this study. The physical properties of additives are shown in Tables (4), and (5). Two proportions of carbon fiber (1% and 0.5%) by weight of asphalt cement and two proportions of lime (2% and 4%) by weight of aggregate were used in this study.

Table (4) Properties of Carbon Fiber (*).

Properties	Results
Form	2.54 cm cut
Density	1.8 gm/cm^3
Tensile modulus	29 psi

(*) Results from Al-Furat Beirut

Table (5) Chemical Composition and Physical Properties of Lime(*).

Chemical composition	***lime***
Sulfuric anhydride (SO_3)	0.82
$Ca(OH)_2$	93.88
Total	94.70
Physical properties	
Apparent specific gravity	2.343

(*) This test from lime factory in Karbala.

Table (6): Job Mix Formula's for Wearing Course of the Selected Sections (*).

Sieve opening (mm)	**Percent Passing**	
	Gradation Shape	
	TRZ (R1)	**ARZ (R9)**
19	100	100
12.5	92	89.5
10	83.1	77.8
4.74	66.9	55.3
2	41.5	40.2
1	28.2	32
0.63	21.4	25
0.25	14.4	15.1
0.125	11.6	12.2
0.075	9.8	9.8

Specification Requirements:

Stability , Kg	1000	1000
Flow , mm	2-6mm	2-5mm
Air Voids %	3-5%	2-5%
Asphalt	4.7±0.3	4.63±0.3
Compaction	>98	>98

(*) Data from the SCRB documents

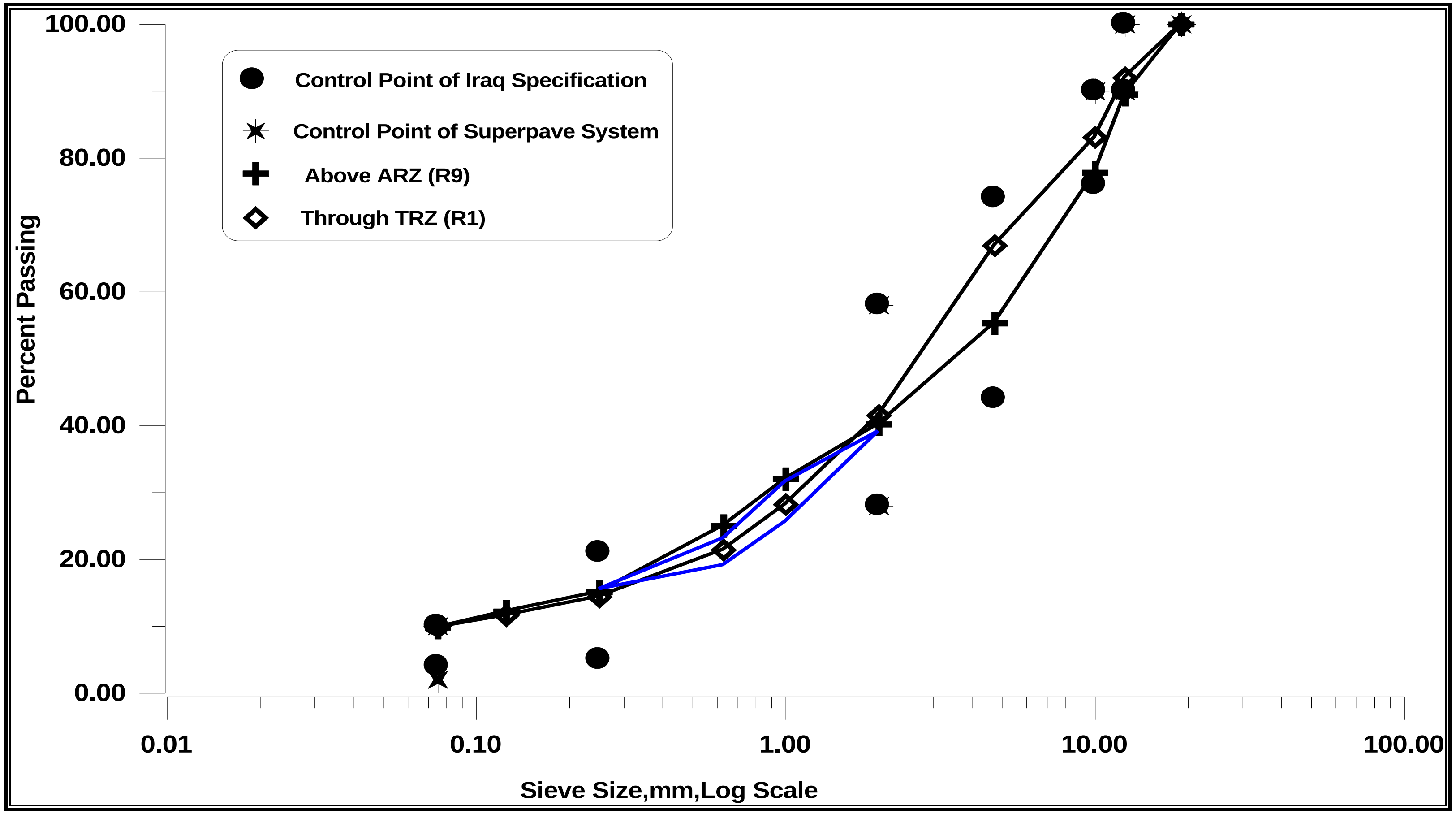

Figure (1) Gradation of Wearing Course for two sections of the Expressway No.1 in Iraq.

5. Mixtures Designs

In order to compare the two-mix design directly. Two types of mixes were prepared with two-type gradation. Three specimens for each mix were prepared, and the average of results was reported.

Marshall Mix Design

Two types of mixes were prepared with two-type gradation. The following two types of mixes were prepared with two optimum asphalt contents of mix design:

- Marshall mixes with optimum asphalt content determined by Marshall Method.
- Marshall mixes with optimum asphalt content determined by Superpave system.

Superpave Mix Design

Two types of mixes were prepared by using two types of gradation. The first type of mixes was prepared with ARZ aggregate gradation and the other mix with TRZ aggregate gradation. To determine the design asphalt content, the first procedure is to measure Gmm. Once the design aggregate structure is identified, the design asphalt content must be determined. Starting with the design aggregate structure and the estimate asphalt content, specimens are prepared at four levels of asphalt content:

- $P\ b_{est}$ -0.5%
- $P\ b_{est}$
- $P\ b_{est}$ +0.5%
- $P\ b_{est}$ +1%

Two compaction specimens were prepared for each asphalt content and the average results were reported .This produces the data for the volumetric analysis, which it can be seen from Table (8).
For the comparison requirements, the following two types of mixes were prepared with the optimum asphalt content:

- Superpave mixes with optimum asphalt content determined by Superpave system.
- Superpave mixes with optimum asphalt content determined by Marshall Method.

6. Moisture Sensitivity

The moisture susceptibility test is used to evaluate HMA against stripping. This test is not a performance based test but serves two purposes . First , it identifies whether a combination of asphalt binder and aggregate is moisture susceptible . Second , it measures the effectiveness of anti-stripping additives .
This test method covers procedures for preparing and testing asphalt concrete specimens to measure the effect of water on the tensile strength of the paving mixture. This test can be used to evaluate the effect of moisture with or without antistripping additives including lime, Portland cement or carbon fiber. The tested specimens are prepared by using the optimum asphalt content. Each set of specimen is divided into two subsets. One subset is tested in dry condition to determine the indirect tensile strength, and the other subset is subjected to vacuum saturation followed by a freeze and warm water soaking cycle. Then, the subset is tested for indirect tensile strength, making at least six specimens for each test, compacted to 7±1% air voids when using Marshall apparatus. For gyratory mixes, at least four specimens were prepared and compacted to 7±0.5% air voids where two specimens were tested dry and two tested after partial saturation and conditioning.

The dry tensile strength is calculate as follows:
ITS(dry) = 2P/πDT ……….(1)
where:
ITS (dry) = tensile strength, psi (Kpa)
P = maximum load, Ibs (Newtons)
D = specimen diameter, inches (mm)
T = specimen height immediately before tensile test, inches (mm).
The wet tensile strength is calculate as follows:
ITS (wet) = 2P/πhd ………..(2)
where:
ITS (wet) = tensile strength, psi (Kpa)
P = maximum load, Ibs (newtons)
d = new specimen diameter after conditioning, inches (mm)
h = specimen height, after conditioning and immediately before tensile test, inches (mm).
The tensile strength ratio is calculate as follows:
TSR = (ITS (WET)/ITS (DRY))*100 …………(3)
where:
TSR = tensile strength ratio, %
ITS (wet) = wet strength or average tensile strength of the moisture – conditioned subset, psi (Kpa), and
ITS (dry) = dry strength or average tensile strength of the dry subset, psi (Kpa).
The recommended minimum tensile strength ratio is 80 and 70 percent, for Superpave and Marshall respectively (*Asphalt Institute,* 1996).

7. Marshall Test

Marshall specimen will be taken to measure stability and flow. Stability of a HMA pavement is its ability to resist shoving and rutting under loads (traffic). A stable pavement maintains its shape and smoothness under repeated loading; and unstable pavement develops ruts (channels), ripples (wash boarding or corrugation), raveling and other signs of shifting of the HMA. Stability and flow value is not the design criteria in Superpave mix design . However, to make a comparison with Marshall mix design, specimens were prepared at optimum of Superpave mix on gyratory compactor and tested for stability and flow values.

8. Asphalt Film Thickness

Recent studies have shown that asphalt mix durability is directly related to asphalt film thickness (*Kandhal, and Chakraborty,* 1996). Asphalt film thickness is directly related to durability and moisture susceptibility of HMA (*Chadbourn, et* al;1999).It is generally agreed that high permeability, high air voids and thin asphalt coatings on the aggregate particles are the primary causes of excessive aging (*Kandhal, et al*;1998).
Because the Superpave mix design often suggests a lower optimum asphalt content than that of the Marshall mix design, the durability of the Superpave mix is questionable and needs to be evaluated (*N.paul and sachiyo*, 2000).

9. Test Program of Asphalt Paving Mixtures

The following variables have been selected in preparing the asphalt concrete mixtures for Marshall and Superpave mixes design:

1) One nominal maximum size (1/2 in. (12.5 mm)) has been selected with two gradation curve (Above Restricted Zone (ARZ) and Through Restricted Zone (TRZ)).
2) One type of crushed aggregate from one source (Al-Taji Quarry).
3) One grade of asphalt cement (40-50) penetration graded from Dourah refinery.
4) Two types of additives (carbon fiber and lime) are used with (1%,0.5%) for carbon fiber by weight of asphalt cement, and (4% , 2%) for lime , by weight of aggregate.
5) Two different asphalt cement contents (optimum of Marshall and optimum of Superpave) are used as a percentage by weight of total mixture , including :

   1/2 in. (12.5mm) nominal maximum size.

   - ARZ gradation (4.63 optimum of Marshall , 4.54 optimum of Superpave)
   - TRZ gradation (4.7 optimum of Marshall , 4.42 optimum of Superpave)
6) One type of filler (cement) is used.
7) One compaction effort (75) blows/end using Marshall test method and one compactive effort (Ninit = 9 , Ndes=135 , Nmax = 220) using Superpave test method for the preparation of specimens for moisture damage test.

10. Results and Discussion

The main objective of this research is to compare between the design of Superpave and Marshall mixes. A detailed laboratory investigation throughout the use of two different mix design procedures is performed for the purpose of comparison. The effectiveness and role of restricted zone on the aggregate gradation were considered in the Superpave mix design. Two types of gradation through and above restricted zone were selected to study the effect of restricted zone on the mixes design. The Marshall test was conducted according to ASTM D 1559 to determine the volumetric properties of specimen. Thus, the optimum asphalt content is one of the critical parameters to be always taken into consideration for the design evaluation. The optimum asphalt content of the HMA is highly dependent on the aggregate characteristics such as gradation and absorption. In Marshall mix design , the optimum asphalt content was to be 4.7% for (R1) TRZ gradation and 4.63% for (R9) ARZ gradation as per the job mix formula for expressway No.1 (SCRB documents). In the Superpave mix design, the optimum asphalt content is found to be 4.42% for (R1) TRZ gradation and 4.54% for (R9) ARZ gradation.

Figure (2) indicate that the Superpave mixes have lower optimum asphalt content than those of Marshall mixes. The lower optimum asphalt content of the Superpave mixes indicates that SGC at 135 gyrations for Ndes applies more compaction energy than the Marshall hammer of 75 blows.

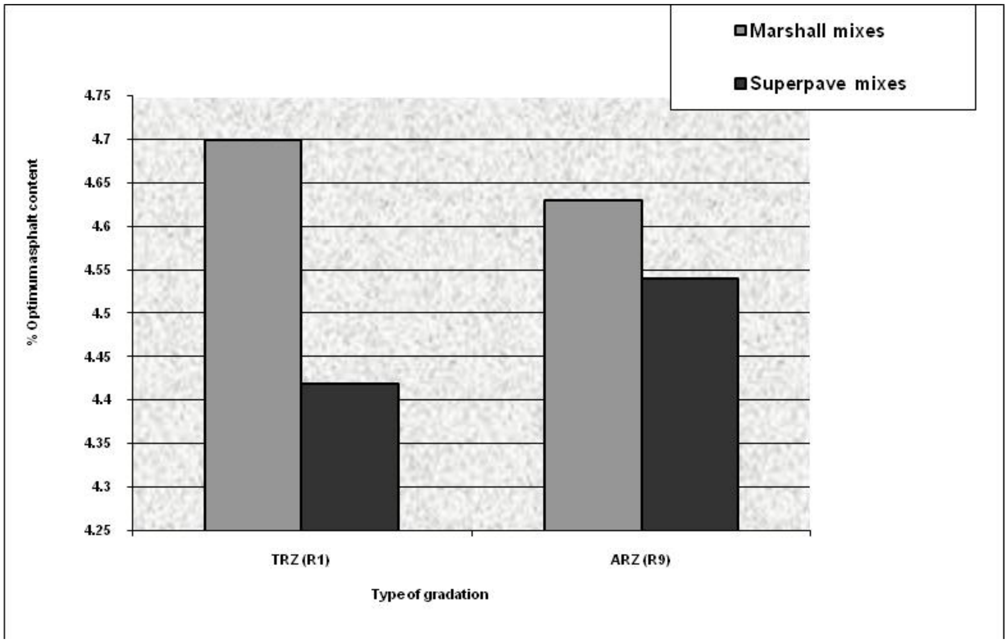

Figure (2) Effect of Mix Design Method on the Optimum Asphalt Content.

It can be seen from Table (7) , that these volumetric properties are checked against the requirements . All the requirements are satisfied .

Table (7) , Volumetric Properties for Marshall Specimens .

Volumetric Properties for Marshall Specimens			
R1 Gradation (TRZ)		R9 Gradation (ARZ)	
A.C (%)	4.7	A.C(%)	4.63
VMA(%)	14.5	VMA(%)	14.85
VTM(%)	3.9	VTM(%)	4.49
VFA(%)	73.1	VFA(%)	69.76
Density	2.353	Density	2.335

For Superpave mix design , it can be seen from Table (8), that the volumetric properties of the Superpave specimens and the gradation meet the criteria of Superpave mix design. Consider that the Superpave system prohibits the gradation to be passing through the restricted zone and recommends the gradation to be below the restricted zone for heavy traffic loads. Figure (3) shows that VTM,VMA and VFA values are lower if compared with Marshall mix design values .

The shearing action during the operation of SGC is efficiently orienting the aggregate into a dense configuration. This may explain the lower value volumetric properties.

Table (8), Volumetric Properties for Superpave Specimens.

Volumetric Properties For Superpave Specimens			
R1 Gradation (TRZ)		R9 Gradation (ARZ)	
A.C(%)	4.42	A.C(%)	4.54
VMA(%)	14	VMA(%)	14.32
VTM(%)	4	VTM(%)	4
VFA(%)	71.42	VFA(%)	72
Density	2.362	Density	2.349

Where:
VMA = Void in mineral aggregate
VTM = Void in total mixes
VFA = Void filled with asphalt
A.C = Asphalt content

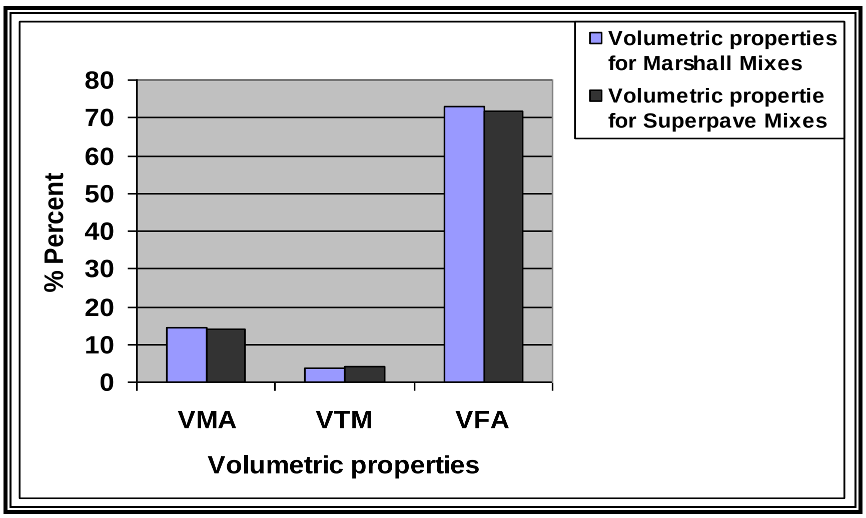

Figure (3) Effect of Mix Design Method on Volumetric Properties.

Stability and flow value is not the design criteria in Superpave mix design . However, to make a comparison with Marshall mix design, specimens were prepared at optimum of Superpave mix on gyratory compactor and tested for stability and flow values. Comparative results are shown in Table (9).

Table (9) Stability and Flow values for each Mix .

Marshall Mixes		
Type of Gradation	**Stability (KN)**	**Flow (mm)**
R1	11.7	4.7
R9	13	2.3
Superpave Mixes		
R1	14.1	4.26
R9	15.7	2.1

It can be seen from Figures (4) to (5) that the stability values of the Superpave mixes are higher than that of Marshall mixes , while the flow values of Superpave mixes are slightly less than that of Marshall mixes . This could be due to differences in compaction technique. The SGC rotates at a constant rate during the compaction, and this characteristic provides around a better orientation of aggregate particles and aggregate interlock. This process simulates the field compaction closely. On the other hand, Marshall compaction hammer provides only the vertical movement.

After studying the effect of restricted zone, it can be seen that ARZ gradation has higher Marshall stability and lower flow value than the TRZ gradation. This can be related to the fact that the ARZ gradation has more internal friction; and increased surface area of aggregate coated with binder as compared with mix of TRZ, therefore, it has the highest stiffness.

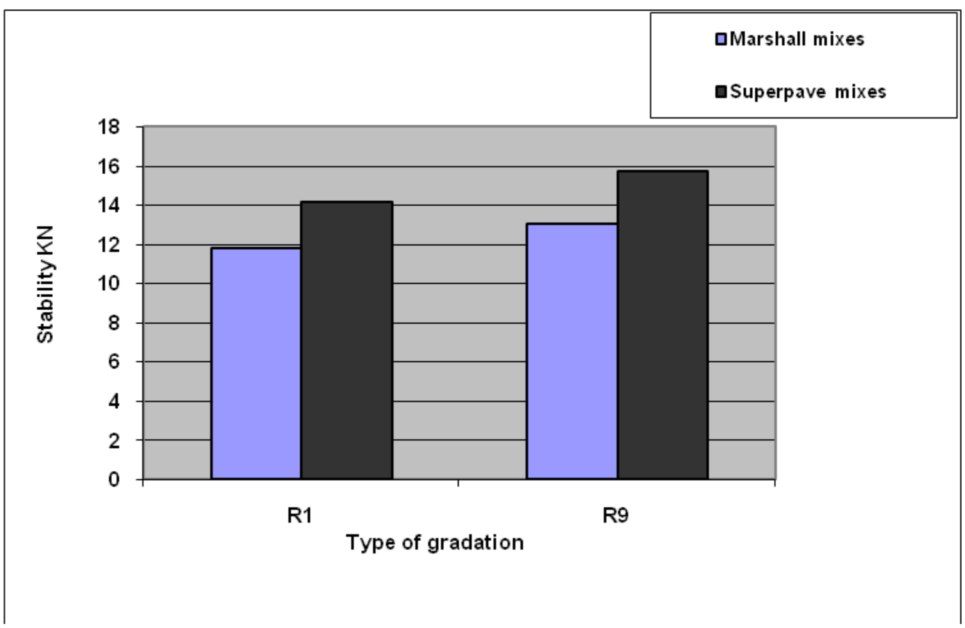

Figure (4) Effect of Type of Gradation on Stability values of Mixes.

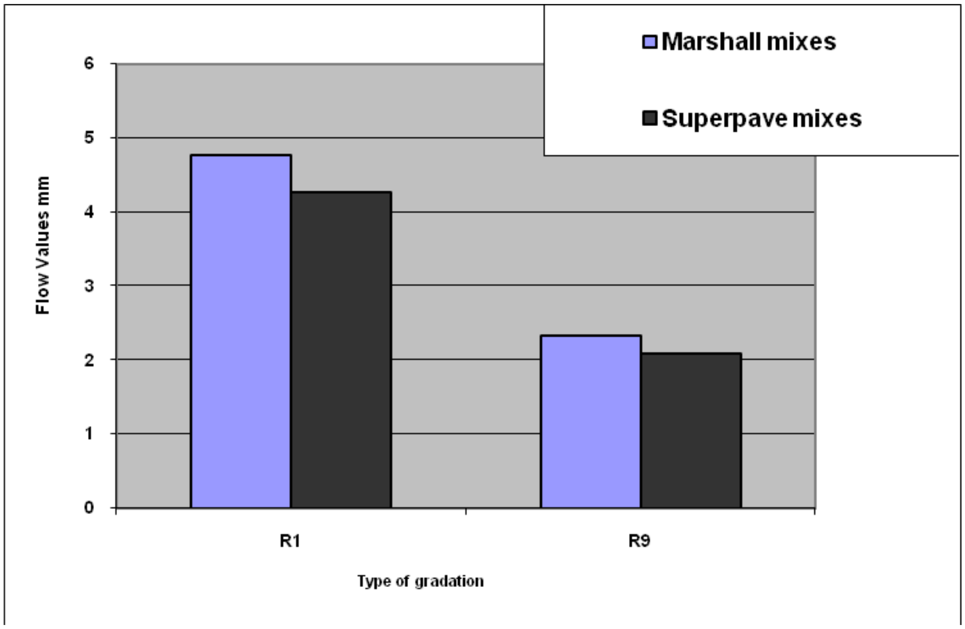

Figure (5) Effect of Type of Gradation on Flow values of Mixes.

Because the Superpave mix design often suggests a lower optimum asphalt content than that of the Marshall mix design, the durability of the Superpave mix is questionable and needs to be evaluated. The method of calculating asphalt film thickness is given in a paper (critical review of VMA requirements in Superpave), presented by Prithvi S.Kandhal , (*Prithv,Rajib*,1998). The average asphalt film thickness for each mix can be calculated using:

VAC = VMA – VTM …………..(4)

Weight of AC = VAC * 1000 * Gb ……………………(5)

$$\text{Weight of aggregate} = \frac{weightofAC}{Pbo} * (100 - Pbo) \quad \ldots\ldots(6)$$

$$\text{Weight of asphalt per kilogram of aggregate} = \frac{weightofAC}{weightofAggregate} \quad \ldots\ldots(7)$$

$$\text{Asphalt Film Thickness} = \frac{weightofAsphaltperkilogramofAggregate}{SurfaceArea * 1000 * Gb} \quad \ldots(8)$$

Where

VAC = volume of asphalt content

Pbo = percent of optimum asphalt content

Gb = specific gravity of asphalt

The film thickness of the Superpave at the optimum asphalt content is determined to be as shown in Table (10). Gradation, VTM and dust content affect film thickness, with dust content having the greatest impact on asphalt film thickness. In this study, the film thickness is mainly affected by the compaction methods and the asphalt contents since the Superpave and Marshall mix designs use the same aggregate gradation. The Marshall mixes yield a higher asphalt film thickness than the Superpave mixes. Therefore, they are more durable to oxidation and polymerization than the Superpave mixtures. Figure (6) shows values of asphalt film thickness for both Superpave and Marshall mixtures. In general, Marshall mixtures show values higher than that of Superpave mixture. This is expected since Marshall mixtures have higher optimum asphalt contents. In addition, Kandhal suggested an optimum film thickness value of 8 microns (*Kandhal, et al*;1998). It is seen from Table (10) ,the average film thickness is less than 8 microns , More detailed results for the Superpave mixes design can be seen in Appendix (A) , Tables A1 to A3.

Table (10) Asphalt Film Thickness for both Mixes.

Asphalt Film Thickness (μ)			
Marshall Mixes		**Superpave Mixes**	
TRZ (R1)	ARZ (R9)	TRZ (R1)	ARZ (R9)
6.22119E-06	5.9491E-06	5.8334E-06	5.82796E-06

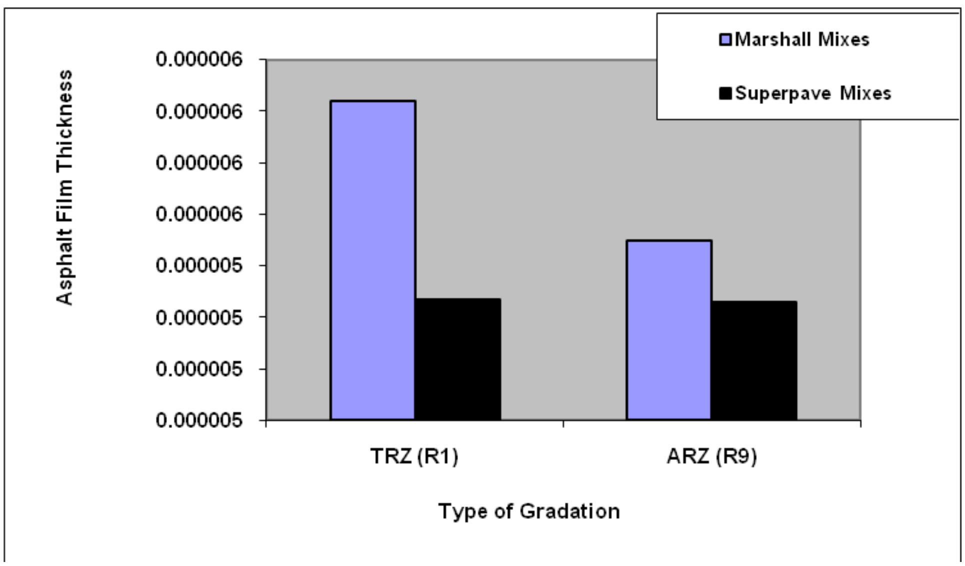

Figure (6) Effect of Mix Design Method on Asphalt Film Thickness.

The indirect tensile strength (ITS) test provides properties that are useful in characterizing moisture susceptibility of hot mix asphalt (HMA). TSR tensile strength ratio is one of the important properties to reflect the strength of asphalt materials against stripping. The TSR value shows the susceptibility of HMA to stripping or reduction in strength under a wet conditioning process.

Figure (7), shows that Marshall mixes with optimum asphalt content determined by Marshall method have higher tensile strength than Marshall mixes with optimum asphalt content determined by Superpave system.

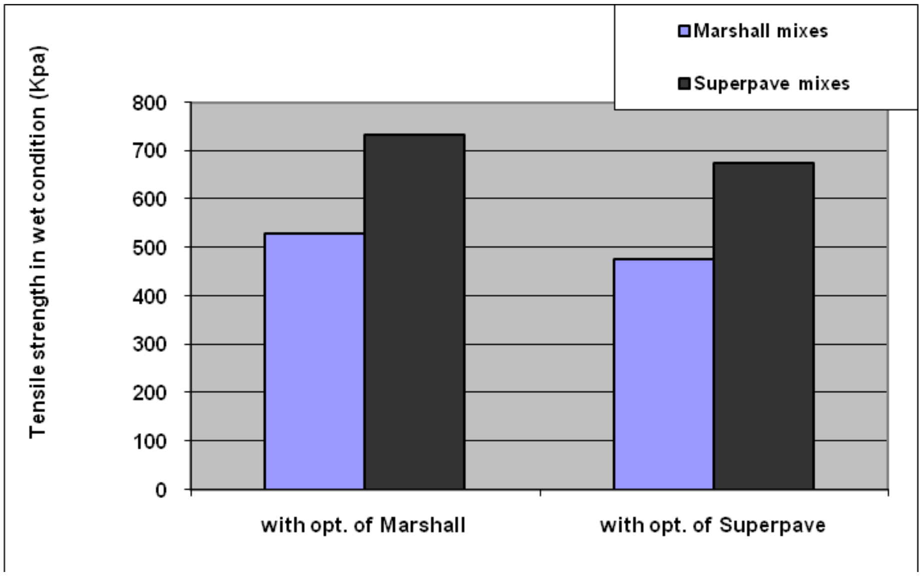

Figure (7) Effect of Asphalt content on Moisture Damage for Marshall and Superpave Mixes.

Evaluation of mixture moisture sensitivity is currently the final step in the Superpave volumetric mix design process. Figures (8) to (9), show the evaluation of the use of the gyratory compactor versus the Marshall hammer for mixture tensile strength ratio (TSR) values. It has been determined that the Superpave mixture gives higher TSR values than Marshall mixtures, the higher TSR values are most likely caused by the different aggregate orientation of the specimen in the SGC and the difficulty of specimen saturation, therefore, Superpave mixes are less affected by water compared to Marshall mixes.

The investigation into the effect of restricted zone, shows that TRZ gradation is less susceptible to moisture damage than the ARZ gradation. This behavior can be attributed to the fact , that TRZ mixture with low air voids , will be less sensitive to moisture damage . After investigating the effect of additives to mixture, it can be seen that mixes with lime have higher TSR values than the mixes without lime. This can be attributed to the fact that when lime is added to hot mix, it reacts with aggregates and strengthening the bond between the asphalt and the aggregate. At the same time, it treats with the aggregate and with the asphalt itself. Lime reacts with highly polar molecules that can otherwise react in the mix to form water-soluble soaps that promote stripping .When those molecules react with lime , they form insoluble salts that no longer attract water (Petersen,et al, 1987) . In addition, the dispersion of the tiny hydrated lime particles throughout the mixes makes them stiffer and tougher, reducing the likelihood of bond between the asphalt cement and the aggregate which will be broken mechanically, even if water is not present. In addition, it can be seen, that the additive of a carbon fiber to HMA mix will also increase the strength of the mixture. It is thought that the addition of carbon fiber to asphalt enhances material strength and fatigue characteristics while adding ductility. Because of their inherent compatibility with asphalt cement and excellent mechanical properties, carbon fibers might offer an excellent potential for asphalt modification (*M.Aren C.* , 2000) . The procedure, which is adopted to prepare modified asphalt can be outlined, as follows, the asphalt cement with known weight is heated in an oven until a temperature of 150˚C, and then the known weight of carbon fiber is mixed with asphalt and kept at temperature of 150˚C.

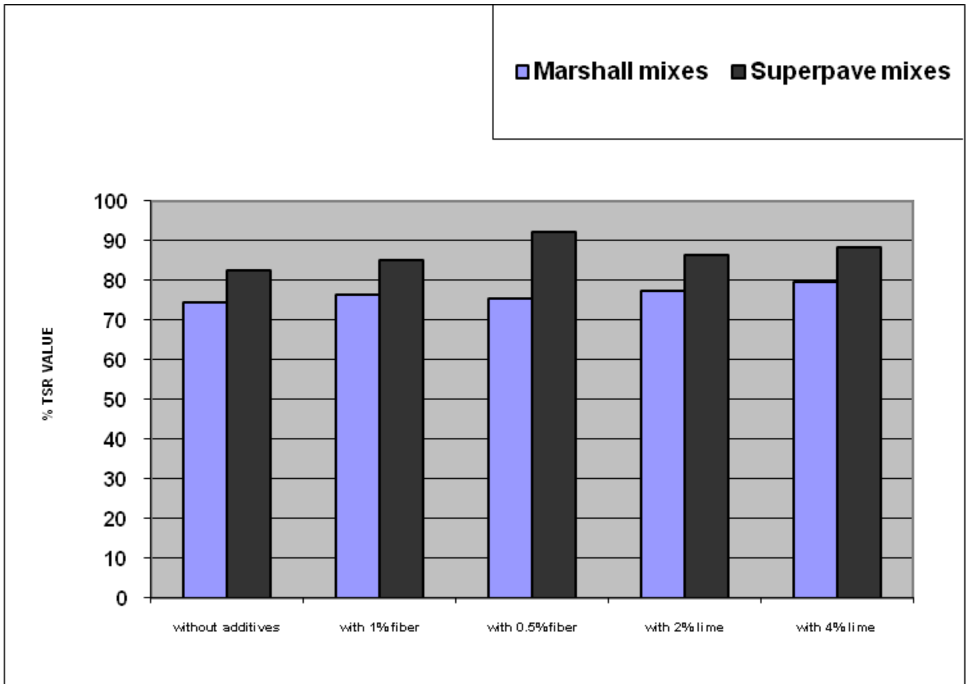

Figure (8) Effect of Mix Design Method on TSR Ratio.

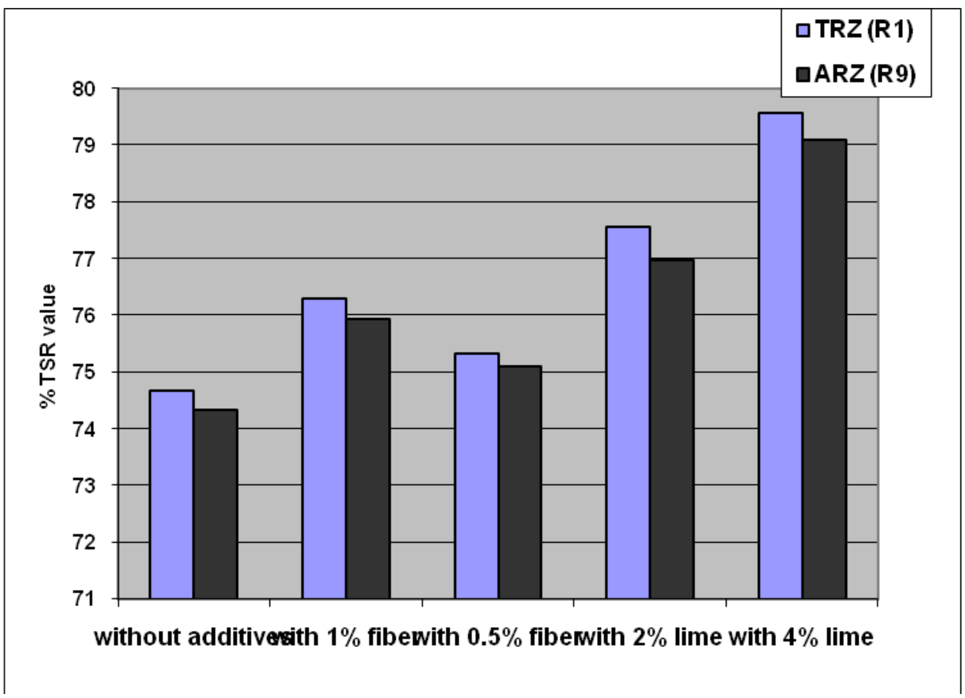

Figure (9) Effect of Gradation on TSR Ratio.

11. Conclusions

1. Superpave achieves lower air void content than Marshall mixes; this prevents additional compaction under traffic, which could result in the wheel path.
2. Superpave mixes yield lower asphalt content than Marshall Mixes. As a result, Superpave mixes are better from the economical point of views than Marshall Mixes.
3. Superpave mixes show better moisture susceptibility than Marshall Mixes.
4. The mixes prepared under the Superpave method pass the Marshall criteria, this indicates that using Superpave method to design and construct pavement should not face unusual difficulties with Superpave mixes.
5. The TRZ gradation blends meet all the Superpave mix design requirements and may be expected to perform adequately.
6. It is concluded that using (carbon fiber and lime) as additives, results; in increase in tensile strength thus more resistance to water action.

12. References

1. Asphalt Institute, (1996), ***" Superpave mix design "*** , Superpave series No.2 (SP -2) .

2. ASTM, (1989), Annual Book of American Society for Testing and Materials , Standard Section 4 , Vol. 04.03.

3. Chad W. Hawkins , P.E. (December , 2004***)," Evaluation of the use of gyratory compacted asphalt specimens for tensile strength ratio (TSR) determination"*** ,South Carolina Department of Transportation .

4. Kandhal P.S. and S. Chakraborty, (January 1996,) ***"Effect of Asphalt Film Thickness on Short and Long Aging of Asphalt Paving Mixtures",*** NCAT Report No.96-1, National Center for Asphalt Technology, Auburn, Al.

5. Chadbourn B.A. , et al, (1999), ***" The Effect of Voids in Mineral Aggregate (VMA) on Hot-Mix Asphalt Pavements",*** Minnesota Department of Transportation, St. Paul, Minnesota.

6. Kandhal, P.S,K.Y.Foo, and R. B. Mallick, (January 1998), ***"A Critical Review of VMA Requirements in Superpave. "*** NCAT Report No.98-1, National Center for Asphalt Technology, Auburn, Al.

7. "Resistance to plastic flow of bituminous mixtures using Marshall apparatus" ,(1993), AASHTO T245 .

8. ***"General Specification for Roads & Bridges "*** , (2003), Iraq State Commission of Roads & Bridges , Department of planning & Studies.

9. N.paul knosla and sachiyo kawaguchi, (2000) , ***" Comparative evaluation of design and performance of Marshall and Superpave mixes "*** Transportation Research Board annual meeting , Washington ,DC .

10. Petersen, J.C ,H and P.M.Harnsbergen, ***"Lime treatment of asphalt to reduce age hardening and improve flow properties"*** Proceedings, AAPT, Vol.56,1987.

11. M. Aren cleven , (2000), ***" Investigation of the properties of carbon fiber modified asphalt mixtures "***, Thesis, M.SC, Michigan Technological University.

12. Vasavi Kanneganti , (2002), ***" Comparison of 19mm Superpave and Marshall base II mixes in west Virginia"*** ,Thesis , M.SC, department of civil and environmental engineering.

Appendix (A)
Superpave Mixes Results

Table (A1), Data Analysis for Superpave Specimens prepared at four level of asphalt cement: (4.532 ±0.5%) and (4.532+1%)

SUPERPAVE DATA ANALYSIS FOR R1										
%VMA	%VFA	ASPHALT CONTENT	air void	GMM @Ndes	GMM	density	Gmm @Nmax	dust proportion	effective asphalt	Gmm @Nini
14.54945	62.19788	4.032	5.5	94.5	2.471467	2.335537	0.9646364	2.439328	4.017499	0.857702
13.81365	74.66275	4.532	3.5	96.5	2.45387	2.367985	0.9750871	2.169306	4.517575	0.867752
14.43009	79.21011	5.032	3	97	2.436522	2.363426	0.9827074	1.953105	5.01765	0.879063
15.04248	83.3804	5.532	2.5	97.5	2.419417	2.358932	0.9844161	1.776094	5.517725	0.879412

Table (A2), Data Analysis for Superpave Specimens prepared at four level of asphalt cement: (4.59 ±0.5%) and (4.59+1%)

SUPERPAVE DATA ANALYSIS FOR R9											
%VMA	%VFA	ASPHALT CONTENT	air void	Gmm Ndes	GMM @Nmax	GMM	density	absorbed asphalt	effective asphalt	dust proportion	Gmm @Nini
14.92381	61.13592	4.09	5.8	94.2	0.961574	2.462718	2.319881	0.0182378	4.072508	2.406379	0.860944
14.18248	73.20638	4.59	3.8	96.2	0.9720557	2.44528	2.352359	0.0182378	4.572599	2.143201	0.871813
14.61565	78.78986	5.09	3.1	96.9	0.9816943	2.428086	2.352815	0.0182378	5.07269	1.931914	0.878843
15.04923	84.05234	5.59	2.4	97.6	0.9854258	2.411132	2.353265	0.0182378	5.572782	1.758547	0.880314

Table (A3), Data analysis for Superpave specimens at initial asphalt content for gradation R1 and R9.

Data Analysis of Superpave Specimens	Gradation R1	Data Analysis of Superpave Specimens	Gradation R9
Gse	2.624	Gse	2.6165
Gsb	2.623	Gsb	2.6153
ASPHALT INITAIL	4.7	ASPHALT INITAIL	4.63
Gmax	2.449	Gmax	2.445
DENSITY	2.3613	DENSITY	2.3496
WEIGHT	4478	WEIGHT	4582
HEIGHT@ N=9	129.2	HEIGHT@N=9	129.2
HEIGHT@ N=135	116	HEIGHT@N=135	115.6
HEIGHT@ N=220	114.8	HEIGHT@N=220	114.8
VMX @Ndes	2049.9	VMX @Ndes	2042.8
VMX@ Nini	2283.2	VMX @Nini	2283.2
GMB Ees.@ Nini	1.9613	GMB EST @Nini	2.0069
GMB Ees.@ Ndes	2.1845	GMB EST @Ndes	2.243
C FACTOR	1.0809	C FACTOR	1.0476
GMB CORR.@ Ndes	2.3613	GMB CORR.@ Ndes	2.3496
GMB CORR.@ Nini	2.1201	GMB CORR.@ Nini	2.1023
%GMM @ Ndes	0.9642	%GMM @Ndes	0.961
%GMM@ Nini	0.8657	%GMM@ Nini	0.8598
VOID AIR	3.5803	VOID AIR	3.9
%VMA	14.208	%VMA	14.317
PB Ees.	4.5321	PB EST	4.59
%VMA Ees.	14.25	%VMA EST	14.327
%VFA Ees.	71.929	%VFA EST	72.082
%GMM Ees.@ Nini	86.149	%GMM EST @Nini	85.884
PBE Effective	4.5177	Pbe Effective	4.5726
density@ Nmax	2.386	density@ Nmax	2.375
air void @ Nmax	2.5725	air void Nmax	2.863
Gmm@ Nmax	97.428	Gmm Nmax	97.137