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SELECTION OF AGGREGATE GRADATION FOR HOT MIX ASPHALT

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BY

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1. ABSTRACT:

Beside the physical properties of aggregate, gradation plays a vital role in durability of asphalt pavement. The selection and effect of gradation on hot mix asphalt performance has long been a contentious issue.

Different agencies specified different gradation for asphalt mixes keeping in view the maximum aggregate size. The asphalt technologist selects the gradation within the specified envelope. The selection of gradation within the envelope does not guarantee optimal durability of the pavement.

Aggregate gradation is the distribution of various particle sizes in the mix. The correct percentage of individual sizes of aggregate in Hot Mix Asphalt (HMA) is of prime importance in establishing the parameters necessary for better performance of HMA.

This paper emphasizes that Federal Highway Administration 0.45 Power Gradation Chart (Maximum Density Line) and Bailey Method be utilized for establishing the gradation curve and Job Mix Formula (JMF) rather than the gradations envelope mentioned in certain Specifications.

2. INTRODUCTION:

Road failures in the form cracking and rutting are a common phenomenon faced throughout the world. Pakistan is also a victim of such failures. It is believed that fatigue cracking is the result of pavement structure and load of the traffic and permanent deformation/ rutting is directly related to shear strength of the mix, which is controlled by aggregate properties. Pavement low temperature cracking is only related to binder properties.

Aggregates constitute approx. 95% of asphalt mix by weight. The durable asphalt mix is attributed to the following:

- Properties of aggregates. (Physical and chemical)
- Properties of binder.
- Percentage of binder used.
- Arrangement of aggregate particles (gradation).

Properties of aggregates and binders are well documented and fulfill the international specified criteria. After selection of aggregates and binder of appropriate quality the most important thing is the arrangement of aggregate particles that is set as per the gradation requirement specified in the Specification.

The gradations specified by different agencies and commonly used are as follows:

ASTM D 3515

Sieve Sizes (mm)	Nominal Maximum Size of Aggregate		
	25 mm	19 mm	12.5 mm
37.5	100	-	-
25	90 ~ 100	100	-
19	-	90 ~ 100	100
12.5	56 ~ 80	-	90 ~ 100
9.5	-	56 ~ 80	-
4.75	29 ~ 59	35 ~ 65	44 ~ 74
2.36	19 ~ 45	23 ~ 49	28 ~ 58
0.300	5 ~ 17	5 ~ 19	5 ~ 21
0.075	1 ~ 7	2 ~ 8	2 ~ 8

National Highway Authority (NHA 1998)

Sieve Sizes (mm)	Nominal Maximum Size of Aggregate		
	25 mm	19 mm	12.5 mm
37.5	100	-	-
25	75 ~ 90	100	-
19	65 ~ 80	90 ~ 100	100
12.5	55 ~ 70	-	75 ~ 90
9.5	45 ~ 60	56 ~ 70	60 ~ 80
4.75	30 ~ 45	35 ~ 50	40 ~ 60
2.36	15 ~ 35	23 ~ 35	20 ~ 40
0.300	5 ~ 15	5 ~ 12	5 ~ 15
0.075	2 ~ 7	2 ~ 8	3 ~ 8

MOC (Kingdom of Saudi Arabia)

Sieve Sizes (mm)	Nominal Maximum Size of Aggregate		
	25 mm	19 mm	12.5 mm
37.5	100	-	-
25	75 ~ 90	100	100
19	65 ~ 80	75 ~ 90	90 ~ 100
12.5	55 ~ 70	65 ~ 80	78 ~ 93
9.5	45 ~ 60	55 ~ 65	57 ~ 72
4.75	31 ~ 46	35 ~ 60	43 ~ 58
2.00	18 ~ 33	20 ~ 35	28 ~ 43
0.425	5 ~ 18	7 ~ 20	13 ~ 28
0.180	3 ~ 13	5 ~ 25	-
0.075	2 ~ 9	3 ~ 7	3 ~ 7

MOC (Sultanate of Oman)

Sieve Sizes (mm)	Nominal Maximum Size of Aggregate				
	Asphalt Base Course		Binder Course	Asphalt Wearing Course	
	Class A	Class B		Class A	Class B
25	100	100	100	-	-
19	60 ~ 90	90 ~ 100	66 ~ 100	100	100
12.5	-	-	-	-	90 ~ 100
9.5	42 ~ 67	60 ~ 80	47 ~ 72	56 ~ 80	73 ~ 93
4.75	25 ~ 50	40 ~ 60	30 ~ 56	35 ~ 56	51 ~ 71
2.36	-	28 ~ 48	-	-	34 ~ 54
2.00	15 ~ 31	-	19 ~ 36	22 ~ 36	-
1.18	-	20 ~ 36	-	-	22 ~ 38
0.6	-	14 ~ 26	-	-	18 ~ 30
0.425	8 ~ 25	-	8 ~ 20	8 ~ 20	-
0.300	-	8 ~ 20	-	-	10 ~ 22
0.150	-	7 ~ 15	-	-	9 ~ 17
0.075	2 ~ 15	2 ~ 8	2 ~ 8	2 ~ 8	2 ~ 8

Asphalt mix prepared from aggregates of same source with uniform physical and chemical properties with same percentage of bitumen but with different gradation will yield different properties and thus will behave differently under similar load and climatic conditions. It is not necessary that asphalt mix prepared by using best quality aggregates and binder content proves to be durable without proper distribution of aggregate particles.

So it is not aggregate/binder properties alone that control the properties of an asphalt mix. It is actually the distribution of aggregate particles forming such a structure that in the presence of bitumen will yield a mix that will not rut/shove under load or become brittle and crack with the passage of time.

3. OBJECTIVES:

The objectives of this paper are to suggest a method for selection of gradation for HMA taking advantage of the international research rather than following the traditional criteria such that the selected gradation could be used to predict the properties of asphalt mix before making trials for JMF.

4. A BRIEF REVIEW ON INTERNATIONAL LITERATURE:

The research on improving the properties of HMA is a continuous process and day-by-day Asphalt Technologist and Pavement Experts are suggesting different criteria for developing durable asphalt mix which can sustain heavy load under adverse conditions. The criteria included for developing a durable mix mainly depend upon the following:

4.1 Particle Size Distribution:

The particle size distribution or gradation of an aggregate is one of the most important characteristics in determining how an aggregate will perform as a pavement material. In HMA, gradation helps to determine almost every important property including stiffness, stability, permeability, workability, fatigue resistance, frictional resistance and resistance to moisture damage. (Roberts et al 1996). Particle size distribution can be achieved by the following methods.

4.1.1 Hit & Trial Method:

Generally hit and trial method is used to select the gradation by keeping the gradation curve in the middle of the specified envelope. This approach sometime brings the gradation line parallel or very close to maximum density line (Fig. 1). *The Asphalt Institute Manual Series MS-2 recommends keeping the gradation curve away from the Maximum Density Line (MDL).*

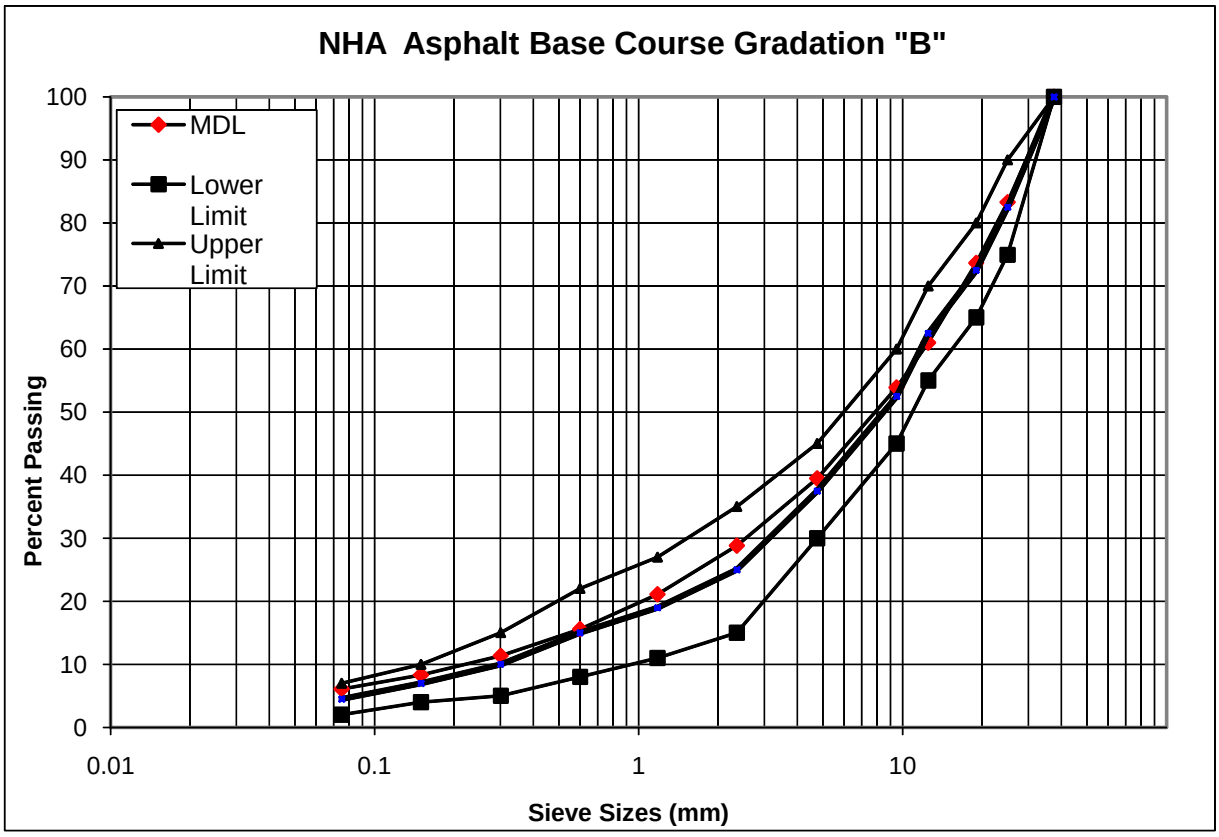


Figure 1

4.1.2 Federal Highway Administration 0.45 Power Gradation Chart:

Federal Highway Administration 0.45 Power Gradation Chart is the most common tool available for asphalt designers but unfortunately not commonly used in Pakistan. (Fig.2) Though the chart is not fully explained in MS-2 but as a general rule it is advised to keep the gradation line away from the maximum density line to increase the VMA. FHWA 0.45 Power Chart is an appropriate tool for establishing the gradation curve for HMA mix, however it is always better to keep the gradation curve away from the MDL due to following reasons:

- The aggregate gradation that follows the maximum density line will have the maximum surface area.
- Due to excess surface area the demand for bitumen will increase and additional bitumen will be required.
- Voids in mineral aggregate (VMA) and air voids will be on lesser side.
- Due to higher bitumen content the mix will have the tendency to compact under load that will ultimately lead to plastic deformation and rutting.

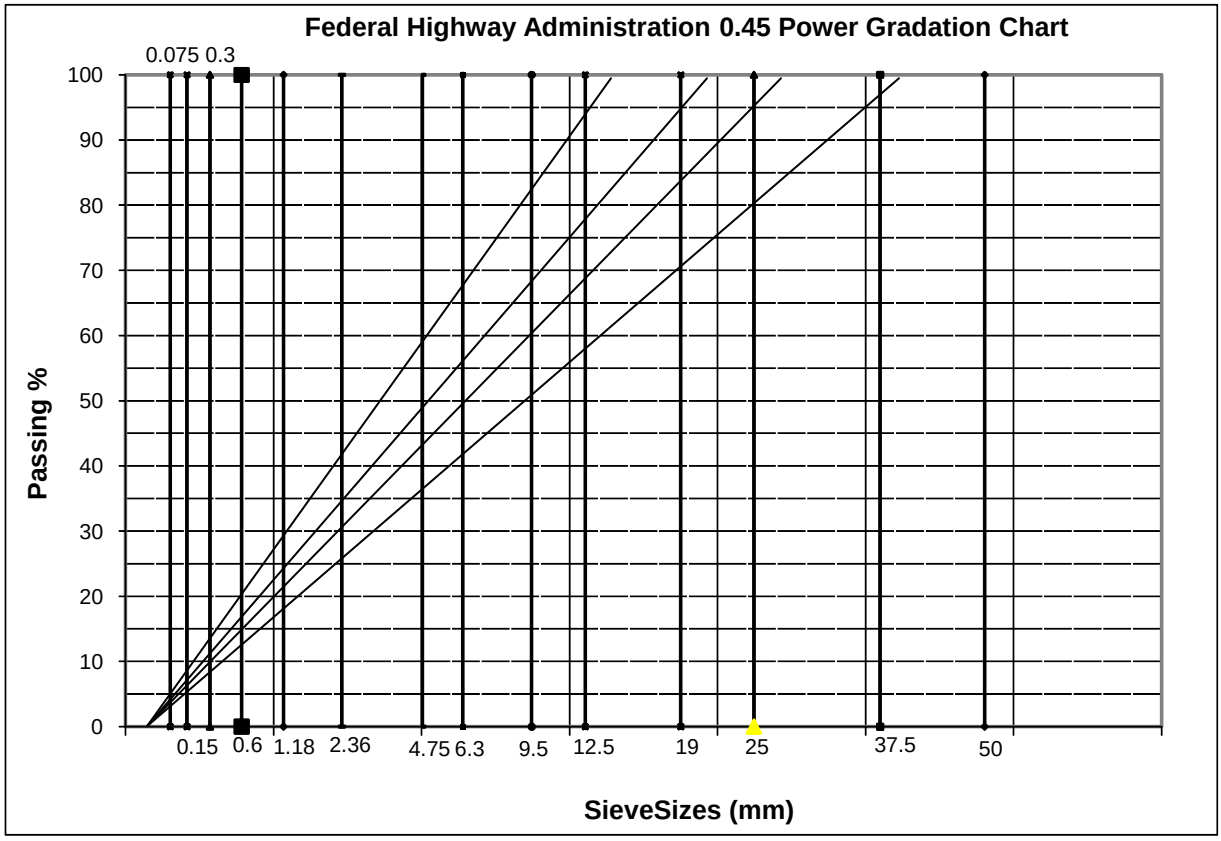


Figure 2:

It is well known fact that most of the asphalt mix designs follow the mid point gradation as specified in most of the Project Specifications without taking into account the MDL.

4.2 Bailey Method for Gradation:

Mr. Robert Bailey (Retired) of Illinois Department of Transportation developed a method known as Bailey Method for adjusting the gradation of aggregates. It is a systemic approach to blend aggregates that also provides proper interlocking and packing within the aggregate particles. Only important points are discussed here as detail of the method is beyond the scope of this paper.

Bailey Method works on two principles:

- Defining coarse and fine aggregate according to nominal maximum size of aggregate (NMSA).
- Aggregate Packing.

4.2.1 Coarse and Fine Aggregates:

Generally coarse aggregate is defined as the material retained on sieve # 4 (4.75mm) and fine aggregate as material passing sieve # 4 (4.75mm) without considering the nominal maximum size of aggregate.

In Bailey Method, coarse and fine depends upon the nominal maximum size of aggregate. In this method the sieve that separates the coarse and fine aggregates is known as **Primary Control Sieve (PCS).**

PCS = NMPS*0.22

where 0.22 is packing constant.

For Nominal Maximum Particle Size (NMPS) of 25mm, PCS = 25 * 0.22 = 5.5. Since the nearest sieve to 5.5mm is 4.75mm, PCS for NMPS of 25mm is 4.75mm sieve. This means that when NMPS is 25mm, coarse aggregate will be considered as the particles retained on 4.75mm sieve and passing will be considered as fine aggregates.

For an NMPS of 12.5mm, PCS = 12.5 * 0.22 = 2.75. Since the nearest sieve to 2.75mm is 2.36mm, PCS for NMPS of 12.5 is 2.36mm sieve. This means that when NMPS is 12.5mm, coarse aggregate will be considered as the particles retained on 2.36mm sieve and passing will be considered as fine aggregates.

In Bailey Method coarse aggregate is separated from fine by PCS, Coarse portion of fine aggregate is separated by Secondary Control Sieve (SCS) and Fine portion of fine aggregate is separated by Tertiary Control Sieve (TCS) using the following:

PCS = NMSA * 0.22

SCS = PCS * 0.22

TCS = SCS * 0.22

Another variable used in Bailey Method is “half sieve” which is half the NMSA. Particles smaller than half sieve are called “interceptor”. Interceptor are too large to fit in the voids created by larger coarse aggregate particles and hence spread them apart. The balance of these particles can be used to adjust the mixture’s volumetric properties. By changing the quantity of interceptor it is possible to change the VMA in the mixture to produce a balanced coarse aggregate structure. With a balanced aggregate structure the mixture should be easy to compact in the field and should perform optimally under load.

CONTROL SIEVES FOR VARIOUS ASPHALT MIXES

	NMPS (mm)					
	37.5	**25**	**19**	**12.5**	**9.5**	**4.75**
Half Sieve	19.0	12.5	9.5	**	4.75	2.36
PCS	9.5	4.75	4.75	2.36	2.36	1.18
SCS	2.36	1.18	1.18	0.6	0.6	0.3
TCS	0.6	0.3	0.3	0.150	0.150	0.075

** The nearest “typical” half sieve for a 12.5 NMPS mixture is 4.75mm. However, the 6.25mm sieve actually serves as the break point. Interpolating the percent passing value for 6.25mm sieve for use in CA Ratio will provide a more representative ratio value.

The packing within the aggregate is evaluated by following three ratios:

- Coarse Aggregate ratio (CA Ratio)

  = (% Passing Half Sieve - % Passing PCS) / (100 - Passing half Sieve)

- Fine Aggregate Coarse Ratio (FA_c Ratio) = % passing SCS / % passing PCS
- Fine Aggregate Fine Ratio (FA_f) = % passing TCS / % passing SCS

	NMPS (mm)					
	37.5	**25**	**19**	**12.5**	**9.5**	**4.75**
CA Ratio	0.80 ~ 0.95	0.70 ~ 0.85	0.60 ~ 0.75	0.50 ~ 0.65	0.40 ~ 0.55	0.30 ~ 0.45
FA_c Ratio	0.35 ~ 0.50	0.35 ~ 0.50	0.35 ~ 0.50	0.35 ~ 0.50	0.35 ~ 0.50	0.35 ~ 0.50
FA_f Ratio	0.35 ~ 0.50	0.35 ~ 0.50	0.35 ~ 0.50	0.35 ~ 0.50	0.35 ~ 0.50	0.35 ~ 0.50

- CA Ratio below the corresponding range suggested in the above mentioned table could indicate a blend that may be prone to segregation.
- An increase in CA Ratio will cause a corresponding increase in air voids and VMA.
- As the CA Ratio increases towards 1.0, VMA will increase.
- If the CA Ratio approaches or goes above 1.0, the coarse aggregate becomes unbalanced and this may cause the mixture to move during compaction, allowing the mat to widen.
- As the ratios FA_c and FA_f increase, the packing of fine aggregates becomes denser and the voids in the mixture decrease.

5. ASPHALT FILM THICKNESS:

Asphalt film thickness is important parameter that is directly related to the selection of gradation of aggregates. Numerous methods are specified to calculate the asphalt film thickness on aggregate particles but Edward and Hveem method is the most widely used.

Various studies dating back to 1950s have attempted to establish an appropriate film thickness for dense graded mixes. Conclusion of the studies includes:

- An average film thickness of 6 ~ 8 microns is recommended for dense graded asphalt mixtures (Campen et al 1959).
- Minimum 8 micron film thickness for asphalt mixes having 4 ~ 5 % air voids (Kandhal et al 1998).
- A dense graded mixture required 4 ~ 6 microns average film thickness (FHWA 1990).

Asphalt film thickness is calculated on effective asphalt content and the surface area of aggregates is determined from the gradation applying the surface area factor. (Edward and Hveem Method)

Following table provides the surface area factor for various sieve sizes as per Edward and Hveem Method. Please note that coarse aggregate had very small effect on surface area as compared to fine aggregates.

SIEVE SIZES (mm)	SURFACE AREA FACTOR
4.750	0.41
2.360	0.82
1.180	1.64
0.600	2.87
0.300	6.14
0.150	12.29
0.075	32.77

Gradation of the mix can be adjusted to have a reasonable thickness of asphalt film.

Most of the Asphalt Technologists/Pavement Experts still believe that for durable asphalt mix the minimum asphalt thickness should be 8 microns.

6. VOIDS IN MINERAL AGGREGATES (VMA):

Voids in mineral aggregates (VMA) are the volume of inter-granular voids space between the aggregate particles of a compacted paving mixture. It includes air voids and volume of effective asphalt content (Robert et-al).

VMA is considered to be the most important mix design parameter, which affects the durability of the asphalt mix. High VMA value allows enough asphalt to be incorporated in the mix to obtain maximum durability without flushing of asphalt.

The importance of VMA in HMA had been known to asphalt technologists since decades and the fact that after the properties of aggregates, VMA is the controlling factor in establishing the durability of an asphalt mix. The key role of gradation in achieving the desired VMA is the other factor that cannot be ignored. The success of stone matrix asphalt (SMA) is primarily due to higher percentage of VMA. For hot mix asphalt VMA can be increased to an appropriate value by adjusting the gradation of aggregates.

7. AIR VOIDS (VTM):

Air voids in total mix are treated as the single, most important characteristic on which the durability of the asphalt mix depends. Asphalt Institute Manual MS-2 specifies a value of 3 to 5 percent for air voids.

Keeping in view the gradation and low asphalt content specified for Marshall Mixes (especially in our National Specifications); it is very difficult to achieve the specified air voids. The problem of fatigue cracking and rutting mainly erupts from poor mix design, with high air voids and low asphalt binder or vice versa. As mentioned earlier, the final mix design should maintain a favorable balance between aggregate gradation and asphalt content. This balance is difficult rather impossible to achieve keeping in view the present procedure for selection of gradation in Marshall Method of Mix Design.

Research has revealed that asphalt mixes with low air voids are more resistant to fatigue cracking than mixes with high air voids.

8. ASPHALT BINDER (%)

Generally the asphalt binder used for asphalt mix in Pakistan is 3 to 5%. Due to excess of fine aggregates and dense gradation this amount of asphalt binder does not satisfy the criteria of an appropriate film thickness around the aggregates. The thin film around the aggregates does not give proper bonding which results in the problems of raveling and potholes at site while a little excess asphalt binder gives rise to rutting as the VMA are on lower side.

It is believed that durability of the asphalt mix depend upon the quantity of asphalt binder and is generally improved by high asphalt binder, well-compacted and impervious mix. Maximum rut resistance is not possible in an aggregate mass until the amount of asphalt coating had reached some critical value. The higher amount of asphalt binder which results in thicker film around the aggregate particles is more resistant to age hardening and thus reduces the problems of raveling and pavement brittleness. Higher amount of asphalt binder also reduces the pore sizes of the interconnected voids making it difficult for air and water to intrude the mix and cause damage.

Sufficient asphalt binder is also necessary to provide proper bonding to the aggregates to overcome the abrasive forces of traffic. It is also acknowledged that proper quantity of asphalt binder is extremely important for fatigue resistance of pavement. As a rule, higher the asphalt content the greater is the fatigue resistant.

9. SELECTION OF GRADATION:

The importance of VMA, VTM, percentage of asphalt binder used and asphalt film thickness in HMA is now internationally acknowledged and the dependence of all these factors upon the gradation or particle size distribution of aggregates is also recognized. The gradation of the aggregate should be so adjusted that VMA, VTM and asphalt film thickness criteria are also met.

As pointed out earlier, generally the mid of the specified range is considered while selecting the gradation for JMF. When such gradation is plotted on 0.45 Power Chart along with MDL either the gradation follows trend of MDL or it flows above the MDL. All these gradation will not meet the CA Ratio, FA_c Ratio or FA_f Ratio as outlined in Bailey Method. Such mixes will result into VMA on lower side and air voids on higher side with segregation.

Some of the mid point gradations as per ASTM D 3515, NHA, KSA MOC, and Sultanate of Oman MOC are shown below:

STANDARD	Maximum Size (mm)	CA Ratio	FA_c Ratio	FA_f Ratio	REMARKS
ASTM D 3515	37.5	0.75	0.56	0.41	Mainly above MDL
	25	0.56	0.53	0.45	do
	19	0.75	0.53	0.39	do
NHA	37.5	0.67	0.51	0.53	At MDL
	25	0.55	0.45	0.45	
	19	0.75	0.57	0.44	Below MDL
MOC KSA	37.5	0.64	0.51	0.51	Above MDL
	25	0.31	0.48	0.52	Zigzag pattern
	25	0.39	0.58	0.59	Do
MOC, SULTANATE OF OMAN	37.5	0.37	0.56	0.71	Below MDL
	25	0.67	0.56	0.5	Above MDL
	25	0.41	0.52	0.56	Below MDL
	19	0.5	0.54	0.49	Do
	19	0.75	0.55	0.54	Above MDL

The above table is self-explanatory and it shows that blindly following mid point gradations will not show any proper sequence in gradation curve. Maximum Density Line (MDL) is an important parameter that needs to be watched carefully and gradation curve closely following this line

must be avoided. Furthermore the gradation line parallel to MDL is also not desirable. Most of the above mentioned gradations did not meet the criteria outlined in Bailey Method.

Results have shown that the gradation curves in which the coarser sieves are on fine side of MDL and finer sieves on coarser side and crosses the MDL somewhere near the boundary of the coarse and fines making an S-curve have shown better performance both in field and laboratory.

Please note that the properties of HMA also depend upon the specific gravities and absorption of aggregates. The present work was carried out with aggregate having bulk specific gravity and effective specific gravity values as 2.7 and 2.728 with asphalt absorption of 0.392%.

Following table reflects the theoretical results of gradation selected keeping in view the S-Curve method on MDL.

Description	Max. Aggregate Size (mm)	Passing # 200 (%)	CA Ratio	FA_c Ratio	FA_f Ratio	% Bitumen	VMA	VTM	VFA	Asphalt Film thickness (microns)	Surface Area (m^2/kg)
ASTM D 3515	37.5	4.0	0.76	0.43	0.47	3.51	12.45	5	59.9	8	3.942
	37.5	5.0	0.71	0.43	0.47	3.76	13.02	5	61.6	8	4.269
	25	4.0	0.73	0.42	0.43	3.65	12.76	5	60.80	8	4.116
	25	5.0	0.73	0.42	0.43	3.9	13.3	5	62.5	8	4.444
	19	5	0.76	0.43	0.47	4.28	13.3	4	69.85	8	4.945
	19	5	0.76	0.43	0.47	4.74	14.3	4	72.03	9	4.945
NHA	37.5	5	0.76	0.43	0.47	3.76	13.03	5	61.6	8	4.269
	25	4	0.71	0.45	0.47	3.59	12.64	5	60.48	8	4.050
	25	5	0.71	0.45	0.47	3.85	13.2	5	62.14	8	4.378
	19	5	0.78	0.44	0.47	4.18	13.04	4	69.33	8	4.814
	19	5	0.78	0.44	0.47	4.4	13.55	4	70.48	8.5	4.814
KSA MOC	37.5	5	0.76	0.43	0.47	3.76	13.02	5	61.6	8	4.269
	25	4	0.8	0.47	0.43	3.63	12.72	5	60.68	8	4.098
	25	5	0.8	0.47	0.43	3.88	13.28	5	62.35	8	4.421
MOC SULTANATE OF OMAN	25	5	0.8	0.47	0.43	3.88	13.28	5	62.35	8	4.421
	19	5	0.76	0.43	0.47	4.28	13.3	4	69.9	8	4.495

The above table clearly shows that if proper homework is done before finalizing the Asphalt Mix Design after taking help from international research the end product will be a durable mix that will not rut/shove or crack at early ages. Once the gradation is finalized, trial mix can be prepared and analyzed. Any difference in the assumed and achieved values can be adjusted accordingly. This systematic approach for selection of gradation not only gives a guideline to the

asphalt technologists/pavement specialists but also helps in improving the quality of asphalt mix.

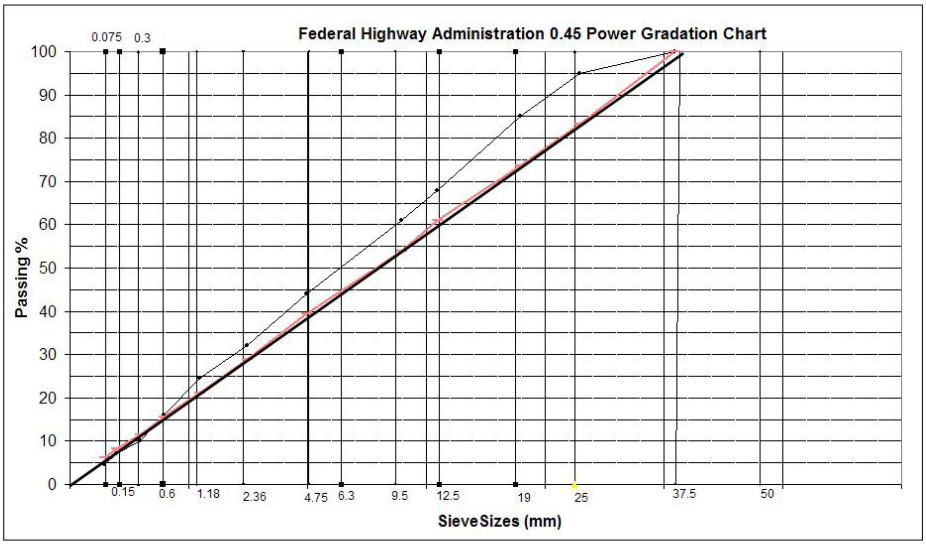
It is worthwhile to note here that for durability of the HMA, enough asphalt binder is needed to give an appropriate asphalt film thickness on aggregate particles. The amount of asphalt sometime seems to be excessive so to avoid the problem of rutting/shoving, 0.1 to 0.3% of cellulose fiber be specified as a precautionary measure. The addition of cellulose fiber will enhance the life of the pavement. ***It should be noted that if cellulose fiber was specified and added to HMA during construction of Lahore-Islamabad Motorway Project, the cracks that appeared in the pavement after 10 years of service, would not have appeared.***

To summarize, the following procedure can be adopted to select gradation for different NMSA for Asphalt Designing:

- On FHWA 0.45 Power Gradation Chart draw Maximum Density Line as per maximum size of aggregate. (Fig. 2)
- Table and graphs in Fig. 3 show a systematic approach for selection of initial gradation for asphalt Job Mix Formula (JMF)
- The gradation is adjusted by keeping the coarser sieves on finer side and finer sieves on coarser side of MDL.
- The adjusted gradation must fulfill the criteria of CA Ratio, FA_c Ratio and FA_f Ratio as outlined in Bailey Method.
- After the gradation is finalized, loose and rodded unit weight of coarse aggregates are determined for selection of chosen unit weight that establishes the volume of coarse aggregate in the aggregate blend and the degree of aggregate packing.
- A worksheet is developed to calculate the properties of HMA (Fig. 4).
- The worksheet will calculate asphalt content, absorbed asphalt, VMA, VFA at the given values of Bulk Specific Gravities and Air Voids.

PROCEDURE FOR SELECTION OF INITIAL GRADATION

ASTM D 3515						CRITERIA AS PER BAILEY METHOD			SPECIFIED
Sieve Size (mm)	MDL	Specs		Mid Point	Tolerance				
37.5	100	**100**	**100**	100		Max. Size	C/A Ratio = (%Passing Half Sieve-% Passing PCS) / (100-Passing Half Sieve)	0.75	**0.70 ~ 0.85**
25	83.3	**90**	**100**	95.0		NMPS			
19	73.6	**80**	**90**	85.0	7±				
12.5	61.0	**56**	**80**	68.0		Half Sieve	FA_c Ratio = % passing SCS / % passing PCS	0.56	**0.35 ~ 0.50**
9.5	53.9	**48**	**74**	61.0					
4.75	39.5	**29**	**59**	44.0		PCS			
2.36	28.8	**19**	**45**	32.0					
1.18	21.1	**14**	**35**	24.5		SCS	FA_f Ratio = % passing TCS / % passing SCS	0.41	**0.35 ~0.50**
0.6	15.6	**10**	**22**	16.0	4±				
0.3	11.4	**5**	**15**	10.0		TCS			
0.15	8.3	3	11	7.0					
0.075	6.1	**2**	**7**	4.5	1±				



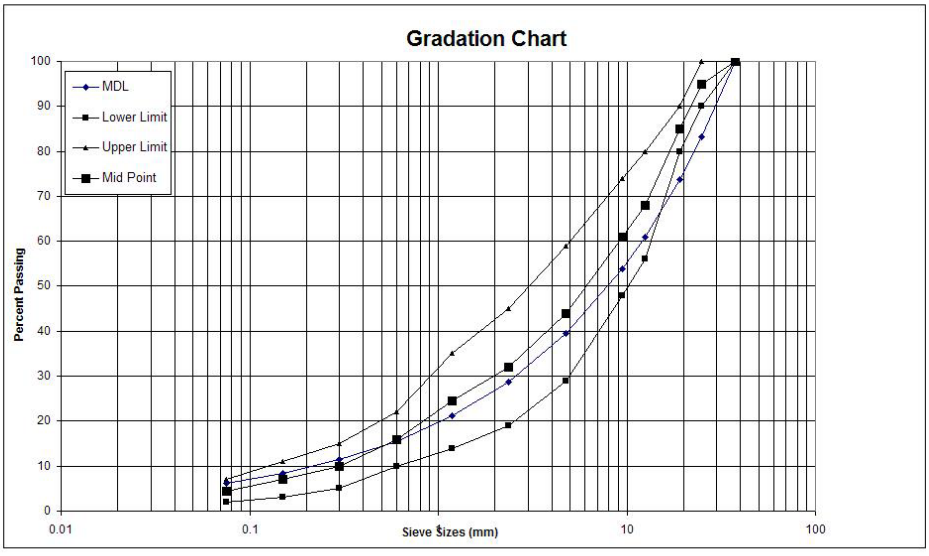


Fig. 3

NATIONAL ENGINEERING SERVICES
PAKISTAN (Pvt) LIMITED.

WORKSHEET FOR HOT MIX ASPHALT (38mm)

PROJECT:

DATE:

MATERIAL		ASTM D 3515				Mid Point Gradation			
						Sieve Analysis and Determination of Surface Area of Total Aggregates by Edwards-Hveem Method			
Specific Gravity of Bitumen	Gb		1.03			Sieve Size	PASSING	SA Factor	SA
Apparent Specific Gravity of Aggregates	Gsa		2.735			(mm)	(%)	m^2/kg	m^2/kg
Bulk Specific Gravity of Aggregates	Gsb		2.700			37.5			
Effective Specific Gravity of Aggregates	Gse	Gsb+F(Gsa-Gsb)	2.728			25			
Factor	F		0.8			19			
Surface Area of Aggregates	SA (m^2/kg)		4.663			12.5			
Average Film Thickness of Asphalt	T_F (microns)		8			9.5		0.41	0.41
Wt. of Effective Asphalt/Unit wt. of Agg.	Wbe	$(SA)*(T_F*10^{-6})*(Gb*1000)$	0.0384			4.75	44	0.41	0.180
Mass of Aggregates	Ws (kg)		1			2.36	32	0.82	0.262
Percent Asphalt Absorbed	Pba (%)	((Gse-Gsb)/(Gse*Gsb))*Gb*100	0.392	0.00392		1.18	24.5	1.64	0.402
Wt. of Absorbed Asphalt	Wba (kg)	Pba*Ws	0.392	0.00392		0.6	16	2.87	0.459
Wt. of Total Asphalt	Wb	Wbe+Wba	0.430	0.04234		0.3	10	6.14	0.614
Volume of Absorbed Asphalt	Vba	Wba/Gb	0.380	0.00380		0.15	7	12.29	0.860
Volume of effective Asphalt	Vbe	Wbe/Gb	0.037	0.03730		0.075	4.5	32.77	1.475
Total Volume of Asphalt	Vb	Vba+Vbe	0.417	0.04110		TOTAL SURFACE AREA (m^2/kg)			4.663
Weight of Mix	Wm	Ws+Wb	1.430	1.04234		Assumed SA			4.00
Total Asphalt Content	Pb (%)	Wb/Wm	0.301	0.04062	4.06				
Effective Asphalt Content	Pbe (%)	Wbe/Wm	0.027	0.03686	3.69				
Bulk Volume of Aggregates	Vsb (M^3)	Ws/Gsb	0.370	0.37037					
Total Volume of Mix (Voidless Mix)	Vmm (M^3)	Vbe+Vsb	0.408	0.40767		CONSTANTS			
Bulk Volume of Mix	Vmb (M^3)	(Vsb+Vbe)/1-Pa	0.429	0.42913		VARIABLES			
Percent Air Voids	Pa (%)		5			CALCULATED			
Voids in Total Mix	VTM (%)	((Vmb-Vmm)/Vmb)*100	5	5					
Voids in Mineral Aggregates	VMA (%)	((Vmb-Vsb)/Vmb)*100	13.69	13.69	13				
Voids Filled with Asphalt	VFA (%)	((VMA-VTM)/VMA)*100	63.48	63.48					
Filler Asphalt Ratio	F/A	P_{200}/Pbe	110.79	1.11					

Fig. 4

Once the gradation is finalized and the properties of the asphalt mix are found to be within the specified limits, trials for complete asphalt design can be prepared and checked accordingly.

Figures 5 to 16 are few examples of selection of gradation and determination of properties for hot mix asphalt (HMA).

Due to limited resources only two trials were carried out to check the properties of asphalt mix by applying the criteria for gradation as mentioned in this paper. The results were quite encouraging as no major difference was observed between assumed and achieved properties. The results are given in table below:

ASTM D 3515 (Maximum Size of Aggregate 37.5 mm) - Data as per Fig. 8

PROPERTIES	ASSUMED	ACHIEVED
Asphalt Content (%)	3.76	3.85
Air Voids (%)	5	5.2
VMA (%)	13	13.2
VFA (%)	61.6	60.6
Asphalt film Thickness (microns)	8	8

ASTM D 3515 (Maximum Size of Aggregate 19.0 mm) - Data as per Fig. 16

PROPERTIES	ASSUMED	ACHIEVED
Asphalt Content (%)	4.74	4.85
Air Voids (%)	4	4.3
VMA (%)	14.3	14.5
VFA (%)	72	70.3
Asphalt film Thickness (microns)	9	9

These asphalt mixes had a glossy look and the asphalt content seemed to be on higher side. Usually such appearance of asphalt mix compels the Material Engineers to lower asphalt content without considering its aftereffects whereas addition of Cellulose fiber (0.1 to 0.3 %) to such a mix is a better choice which will also increase durability of the mix.

10. RECOMMENDATIONS:

The recommendations in the highlight of the paper are as follows:

- Federal Highway Authority (FWHA) 0.45 Power Gradation Chart should be used for selection of gradation for HMA rather than the traditional curves.
- Maximum size of aggregate and maximum passing percentage at sieve 0.075mm should be specified instead of specifying complete ranges for various sieve sizes.
- Minimum coating of asphalt for Asphalt Base Course and Asphalt Wearing Courses should be 8 and 9 microns respectively.
- Addition of Cellulose fiber should be made mandatory for all asphalt mixes.

- The percent air voids in total mix (VTM) for Asphalt Base Course and Asphalt Wearing Course should be kept at 4 ~ 6% and 3 ~ 5% respectively.
- The JMF limits applied to combined gradations need to be revised to some lower limits for better quality control.

Bailey Method for selection of gradation should also be incorporated in our National Specifications after some further work to check its validity for the aggregate of different origins and sources.

11. FURTHER RESEARCH AND VALIDATION

Whilst the recommended criteria for selection of gradations for HMA can be expected to produce an effective hot mix asphalt, further work will be required to refine the suggested limits and to test the sensitivity of the performance in the road to changes in mix composition and other parameters.

REFERENCES:

1. General Specifications 1998, National Highway Authority, Pakistan.
2. General Specifications for Road and Bridges, Ministry of Communications, Kingdom of Saudi Arabia.
3. Standard Specifications for Road and Bridges, Sultanate of Oman.
4. Mix Design Methods, Asphalt Institute Manual Series No. 2 (MS-2) 6th Edition.
5. Bailey Method for Gradation in HMA Mixture Design,

   By: William R Vavrik, Applied Research Associates, Inc.

   Gerald Hubber, Heritage Research Group.

   Samuel H Carpenter, University of Illinois at Urbana-Champaign.

   Robert Bailey, Materials Engineer, (Retired).
6. Investigation of Bailey Method for the Design and Analysis of Dense Graded HMAC using Oregon Aggregates. Final Report SPR-304-311

   By: Garry Thompson PE, Asphalt pavement Association of Oregon (APAO), Sept.2006.
7. Field Verification Process for Open Graded HMAC Mixes. Final Report SPR-304-051)

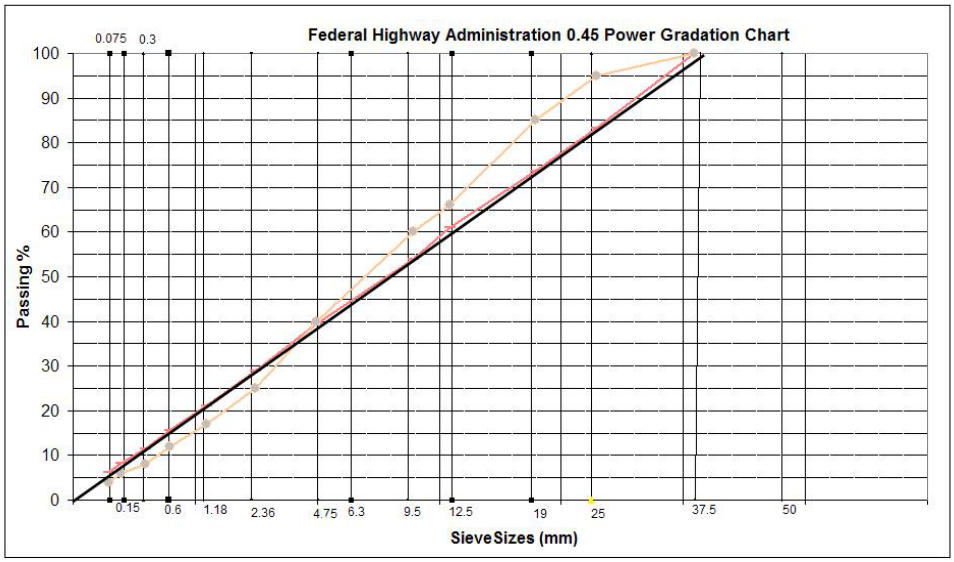
   By: Gary Thompson, Asphalt Pavement Association of Oregon (APAO).

   Mike Remily, Oregon Department of Transportation (ODOT) Pavement Series, July 2002.
8. The Effect of Voids in Mineral Aggregate (VMA) on Hot Mix Asphalt Pavement. Final Report.

   By: Bruce A Chadbourn, Eugene L. Skok Jr. David E Newcomb, Bentia L Crow, Samantha Spindler

PROCEDURE FOR SELECTION OF INITIAL GRADATION

ASTM D 3515						CRITERIA AS PER BAILEY METHOD			SPECIFIED
Sieve Size (mm)	MDL	Specs		Mid Point	Tolerance				
37.5	100	**100**	**100**	100		Max. Size	C/A Ratio = (%Passing Half Sieve-% Passing PCS) / (100-Passing Half Sieve)	0.76	**0.70 ~ 0.85**
25	83.3	**90**	**100**	95.0		NMPS			
19	73.6	**80**	**90**	85.0	7±				
12.5	61.0	**56**	**80**	66.0		Half Sieve	FA_c Ratio = % passing SCS / % passing PCS	0.43	**0.35 ~ 0.50**
9.5	53.9	**48**	**74**	60.0					
4.75	39.5	**29**	**59**	40.0		PCS			
2.36	28.8	**19**	**45**	25.0					
1.18	21.1	**14**	**35**	17.0		SCS	FA_f Ratio = % passing TCS / % passing SCS	0.47	**0.35 ~0.50**
0.6	15.6	**10**	**22**	12.0	4±				
0.3	11.4	**5**	**15**	8.0		TCS			
0.15	8.3	3	11	6.0					
0.075	6.1	**2**	**7**	4.0	1±				



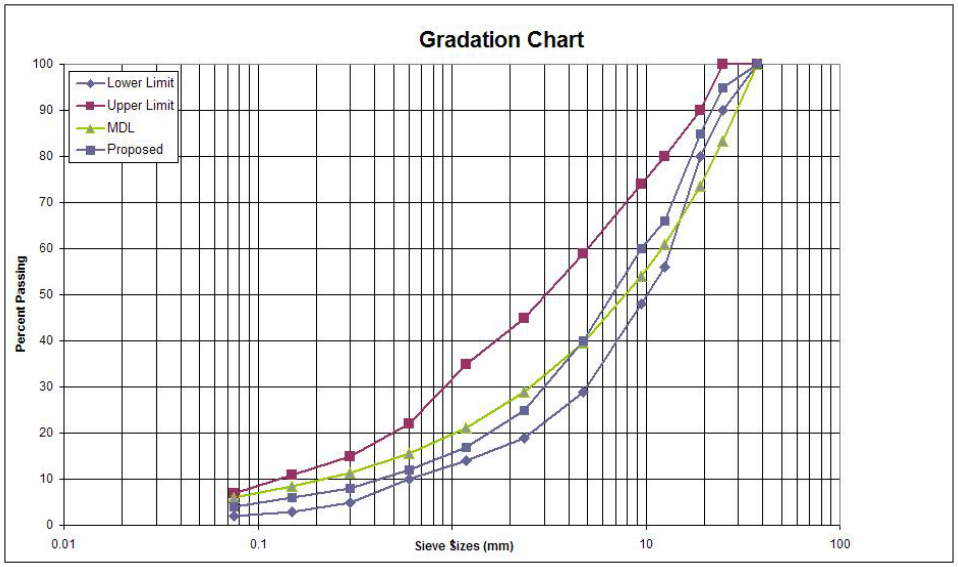


Fig. 5

NATIONAL ENGINEERING SERVICES
PAKISTAN (Pvt) LIMITED.

WORKSHEET FOR HOT MIX ASPHALT (38mm)

PROJECT:

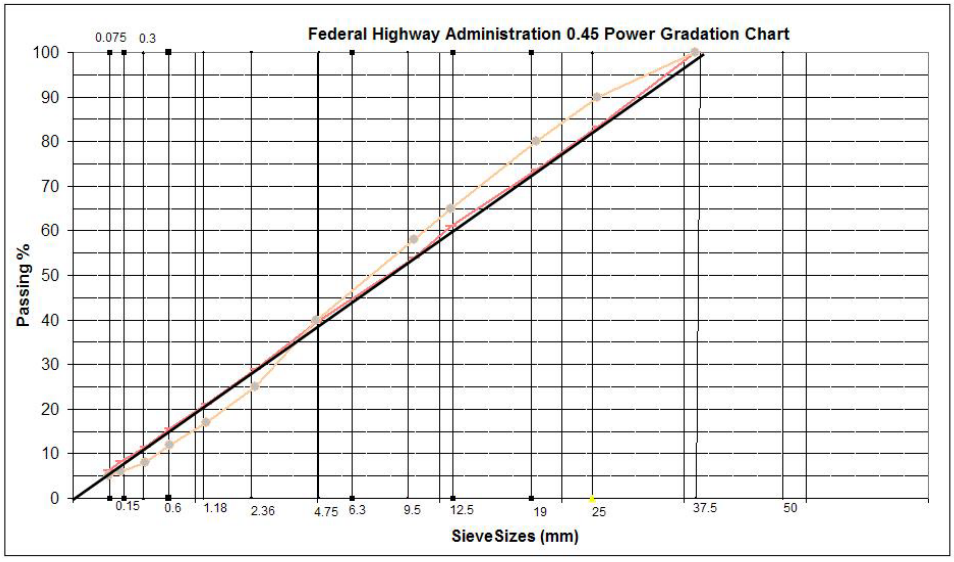
DATE:

MATERIAL		ASTM D 3515				Proposed			
Specific Gravity of Bitumen	Gb		1.03			Sieve Analysis and Determination of Surface Area of Total Aggregates by Edwards-Hveem Method			
Apparent Specific Gravity of Aggregates	Gsa		2.735						
Bulk Specific Gravity of Aggregates	Gsb		2.700			Sieve Size	PASSING	SA Factor	SA
Effective Specific Gravity of Aggregates	Gse	Gsb+F(Gsa-Gsb)	2.728			(mm)	(%)	m^2/kg	m^2/kg
Factor	F		0.8			37.5			
Surface Area of Aggregates	SA (m^2/kg)		3.942			25			
Average Film Thickness of Asphalt	T_F (microns)		8			19			
Wt. of Effective Asphalt/Unit wt. of Agg.	Wbe	(SA)*(T_F*10^{-5})*(Gb*1000)	0.0325			12.5			
Mass of Aggregates	Ws (kg)		1			9.5		0.41	0.41
Percent Asphalt Absorbed	Pba (%)	((Gse-Gsb)/(Gse*Gsb))*Gb*100	0.392	0.003915		4.75	**40**	0.41	0.164
Wt. of Absorbed Asphalt	Wba (kg)	Pba*Ws	0.392	0.003915		2.36	25	0.82	0.205
Wt. of Total Asphalt	Wb	Wbe+Wba	0.424	0.0364		1.18	**17**	1.64	0.279
Volume of Absorbed Asphalt	Vba	Wba/Gb	0.380	0.003801		0.6	12	2.87	0.344
Volume of effective Asphalt	Vbe	Wbe/Gb	0.032	0.031533		0.3	**8**	6.14	0.491
Total Volume of Asphalt	Vb	Vba+Vbe	0.412	0.035334		0.15	6	12.29	0.737
Weight of Mix	Wm	Ws+Wb	1.424	1.0364		0.075	4	32.77	1.311
Total Asphalt Content	Pb (%)	Wb/Wm	0.298	0.035116	3.51	TOTAL SURFACE AREA (m^2/kg)			3.942
Effective Asphalt Content	Pbe (%)	Wbe/Wm	0.023	0.031338	3.13	Assumed SA			4.00
Bulk Volume of Aggregates	Vsb (M^3)	Ws/Gsb	0.370	0.37037					
Total Volume of Mix (Voidless Mix)	Vmm (M^3)	Vbe+Vsb	0.402	0.401903		CONSTANTS			
Bulk Volume of Mix	Vmb (M^3)	(Vsb+Vbe)/1-Pa	0.423	0.423056		VARIABLES			
Percent Air Voids	Pa (%)		5			CALCULATED			
Voids in Total Mix	VTM (%)	((Vmb-Vmm)/Vmb)*100	5	5					
Voids in Mineral Aggregates	VMA (%)	((Vmb-Vsb)/Vmb)*100	12.45	12.45	13				
Voids Filled with Asphalt	VFA (%)	((VMA-VTM)/VMA)*100	59.85	59.85					
Filler Asphalt Ratio	F/A	P_{200}/Pbe	113.91	1.14					

Fig. 6

PROCEDURE FOR SELECTION OF INITIAL GRADATION

ASTM D 3515						CRITERIA AS PER BAILEY METHOD			SPECIFIED
Sieve Size (mm)	MDL	Specs		Mid Point	Tolerance				
37.5	100	**100**	**100**	100		Max. Size NMPS	C/A Ratio = (%Passing Half Sieve-% Passing PCS) / (100-Passing Half Sieve)	0.71	**0.70 ~ 0.85**
25	83.3	**90**	**100**	90.0					
19	73.6	**80**	**90**	80.0	7±				
12.5	61.0	**56**	**80**	65.0		Half Sieve	FA_c Ratio = % passing SCS / % passing PCS	0.43	**0.35 ~ 0.50**
9.5	53.9	**48**	**74**	58.0					
4.75	39.5	**29**	**59**	40.0		PCS			
2.36	28.8	**19**	**45**	25.0					
1.18	21.1	**14**	**35**	17.0		SCS	FA_f Ratio = % passing TCS / % passing SCS	0.47	**0.35 ~0.50**
0.6	15.6	**10**	**22**	12.0	4±				
0.3	11.4	**5**	**15**	8.0		TCS			
0.15	8.3	3	11	6.0					
0.075	6.1	**2**	**7**	5.0	1±				



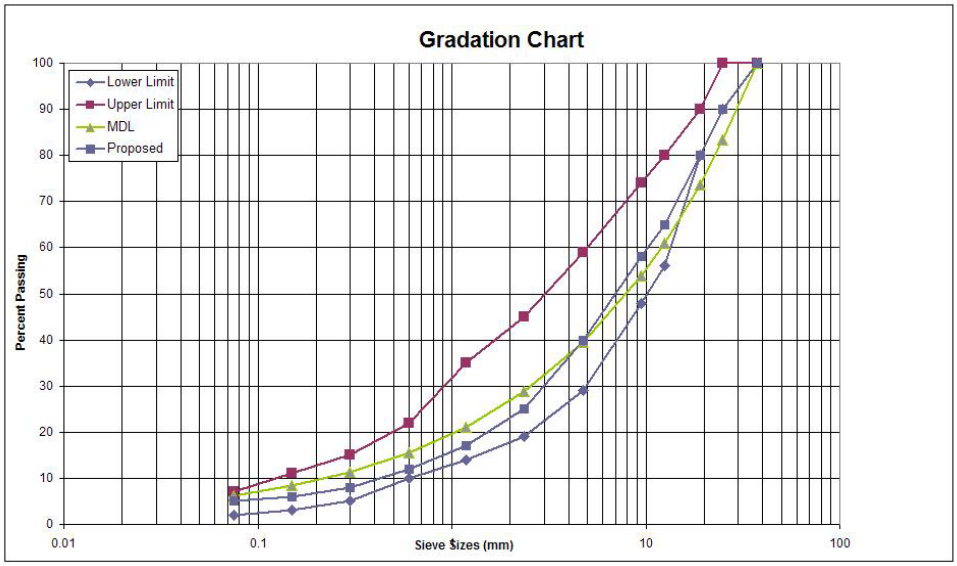


Fig. 7

NATIONAL ENGINEERING SERVICES
PAKISTAN (Pvt) LIMITED.

WORKSHEET FOR HOT MIX ASPHALT (38mm)

PROJECT:

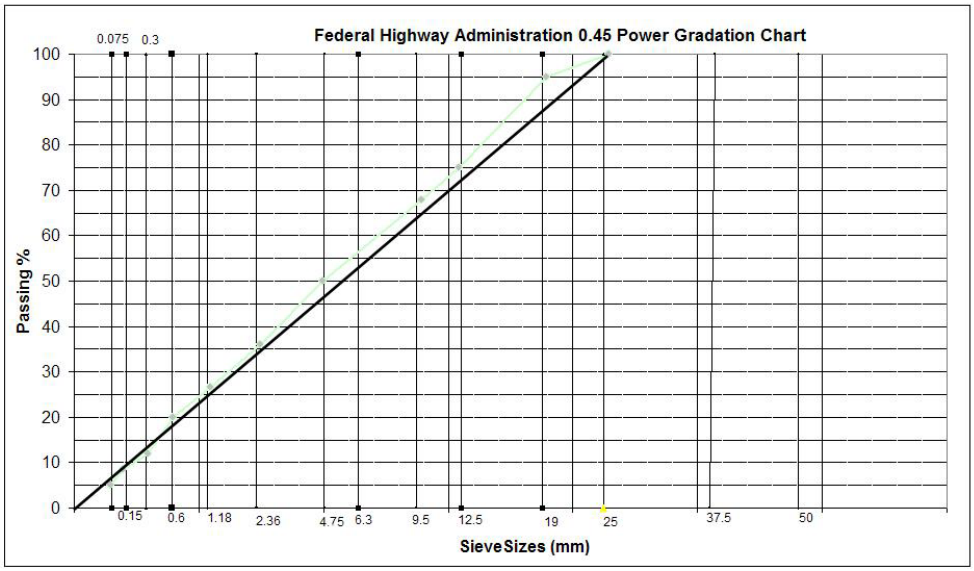
DATE:

MATERIAL		ASTM D 3515				Proposed			
Specific Gravity of Bitumen	Gb		1.03			Sieve Analysis and Determination of Surface Area of Total Aggregates by Edwards-Hveem Method			
Apparent Specific Gravity of Aggregates	Gsa		2.735						
Bulk Specific Gravity of Aggregates	Gsb		2.700			Sieve Size	PASSING	SA Factor	SA
Effective Specific Gravity of Aggregates	Gse	Gsb+F(Gsa-Gsb)	2.728			(mm)	(%)	m^2/kg	m^2/kg
Factor	F		0.8			37.5			
Surface Area of Aggregates	SA (m^2/kg)		4.269			25			
Average Film Thickness of Asphalt	T_F (microns)		8			19			
Wt. of Effective Asphalt/Unit wt. of Agg.	Wbe	(SA)*(T_F*10^{-6})*(Gb*1000)	0.0352			12.5			
Mass of Aggregates	Ws (kg)		1			9.5		0.41	0.41
Percent Asphalt Absorbed	Pba (%)	((Gse-Gsb)/(Gse*Gsb))*Gb*100	0.392	0.003915		4.75	**40**	0.41	0.164
Wt. of Absorbed Asphalt	Wba (kg)	Pba*Ws	0.392	0.003915		2.36	25	0.82	0.205
Wt. of Total Asphalt	Wb	Wbe+Wba	0.427	0.0391		1.18	**17**	1.64	0.279
Volume of Absorbed Asphalt	Vba	Wba/Gb	0.380	0.003801		0.6	12	2.87	0.344
Volume of effective Asphalt	Vbe	Wbe/Gb	0.034	0.034154		0.3	**8**	6.14	0.491
Total Volume of Asphalt	Vb	Vba+Vbe	0.414	0.037956		0.15	6	12.29	0.737
Weight of Mix	Wm	Ws+Wb	1.427	1.0391		0.075	5	32.77	1.639
Total Asphalt Content	Pb (%)	Wb/Wm	0.299	0.037624	3.76	TOTAL SURFACE AREA (m^2/kg)			4.269
Effective Asphalt Content	Pbe (%)	Wbe/Wm	0.025	0.033855	3.39	Assumed SA			4.00
Bulk Volume of Aggregates	Vsb (M^3)	Ws/Gsb	0.370	0.37037					
Total Volume of Mix (Voidless Mix)	Vmm (M^3)	Vbe+Vsb	0.405	0.404525		CONSTANTS			
Bulk Volume of Mix	Vmb (M^3)	(Vsb+Vbe)/1-Pa	0.426	0.425816		VARIABLES			
Percent Air Voids	Pa (%)		5			CALCULATED			
Voids in Total Mix	VTM (%)	((Vmb-Vmm)/Vmb)*100	5	5					
Voids in Mineral Aggregates	VMA (%)	((Vmb-Vsb)/Vmb)*100	13.02	13.02	13				
Voids Filled with Asphalt	VFA (%)	((VMA-VTM)/VMA)*100	61.60	61.60					
Filler Asphalt Ratio	F/A	P_{200}/Pbe	132.90	1.33					

Fig. 8

PROCEDURE FOR SELECTION OF INITIAL GRADATION

ASTM D 3515						CRITERIA AS PER BAILEY METHOD		SPECIFIED
Sieve Size (mm)	MDL	Specs		Mid Point	Tolerance			
						C/A Ratio = (%Passing Half Sieve-% Passing PCS) / (100-Passing Half Sieve)	0.56	0.70 ~ 0.85
25	100.0	100	100	100.0		Max. Size		
19	88.4	90	100	95.0	7±	NMPS		
12.5	73.2	65	85	75.0		FA_c Ratio = % passing SCS / % passing PCS	0.53	0.35 ~ 0.50
9.5	64.7	56	80	68.0		Half Sieve		
4.75	47.4	35	65	50.0		PCS		
2.36	34.6	23	49	36.0				
1.18	25.3	16	37	26.5		SCS	FA_f Ratio = % passing TCS / % passing SCS	0.45	0.35 ~0.50
0.6	18.7	11	29	20.0	4±			
0.3	13.7	5	19	12.0		TCS		
0.15	10.0	4	13	8.5				
0.075	7.3	2	8	5.0	1±			



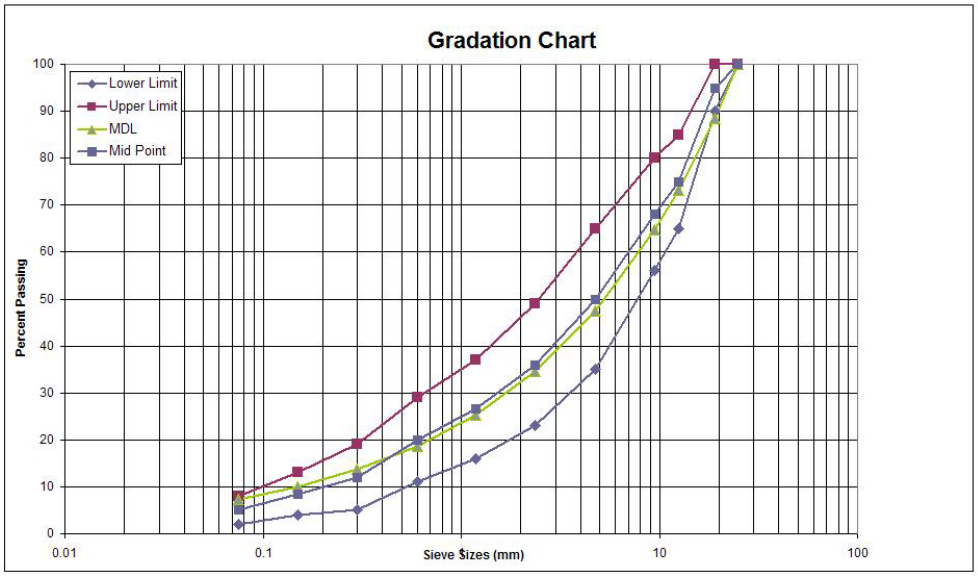


Fig. 9

NATIONAL ENGINEERING SERVICES
PAKISTAN (Pvt) LIMITED.

WORKSHEET FOR HOT MIX ASPHALT (25mm)

PROJECT:

DATE:

MATERIAL		ASTM D 3515				Mid Point
Specific Gravity of Bitumen	Gb		1.03			Sieve Analysis and Determination of Surface Area of Total Aggregates by Edwards-Hveem Method
Apparent Specific Gravity of Aggregates	Gsa		2.735			
Bulk Specific Gravity of Aggregates	Gsb		2.700			
Effective Specific Gravity of Aggregates	Gse	Gsb+F(Gsa-Gsb)	2.728	2.718		
Factor	F		0.8			
Surface Area of Aggregates	SA (m^2/kg)		5.339			
Average Film Thickness of Asphalt	T_F (microns)		8			
Wt. of Effective Asphalt/Unit wt. of Agg.	Wbe	(SA)*(T_F*10^{-6})*(Gb*1000)	0.0440			
Mass of Aggregates	Ws (kg)		1			
Percent Asphalt Absorbed	Pba (%)	((Gse-Gsb)/(Gse*Gsb))*Gb*100	0.392	0.00392		
Wt. of Absorbed Asphalt	Wba (kg)	Pba*Ws	0.392	0.00392		
Wt. of Total Asphalt	Wb	Wbe+Wba	0.436	0.04791		
Volume of Absorbed Asphalt	Vba	Wba/Gb	0.380	0.00380		
Volume of effective Asphalt	Vbe	Wbe/Gb	0.043	0.04271		
Total Volume of Asphalt	Vb	Vba+Vbe	0.423	0.04651		
Weight of Mix	Wm	Ws+Wb	1.436	1.04791		
Total Asphalt Content	Pb (%)	Wb/Wm	0.303	0.04572	4.57	
Effective Asphalt Content	Pbe (%)	Wbe/Wm	0.031	0.04198	4.20	
Bulk Volume of Aggregates	Vsb (M^3)	Ws/Gsb	0.370	0.37037		
Total Volume of Mix (Voidless Mix)	Vmm (M^3)	Vbe+Vsb	0.413	0.41308		
Bulk Volume of Mix	Vmb (M^3)	(Vsb+Vbe)/1-Pa	0.435	0.43482		
Percent Air Voids	Pa (%)		5			
Voids in Total Mix	VTM (%)	((Vmb-Vmm)/Vmb)*100	5	5		
Voids in Mineral Aggregates	VMA (%)	((Vmb-Vsb)/Vmb)*100	14.82	14.82	13	
Voids Filled with Asphalt	VFA (%)	((VMA-VTM)/VMA)*100	66.27	66.27		
Filler Asphalt Ratio	F/A	P_{200}/Pbe	109.37	1.09		

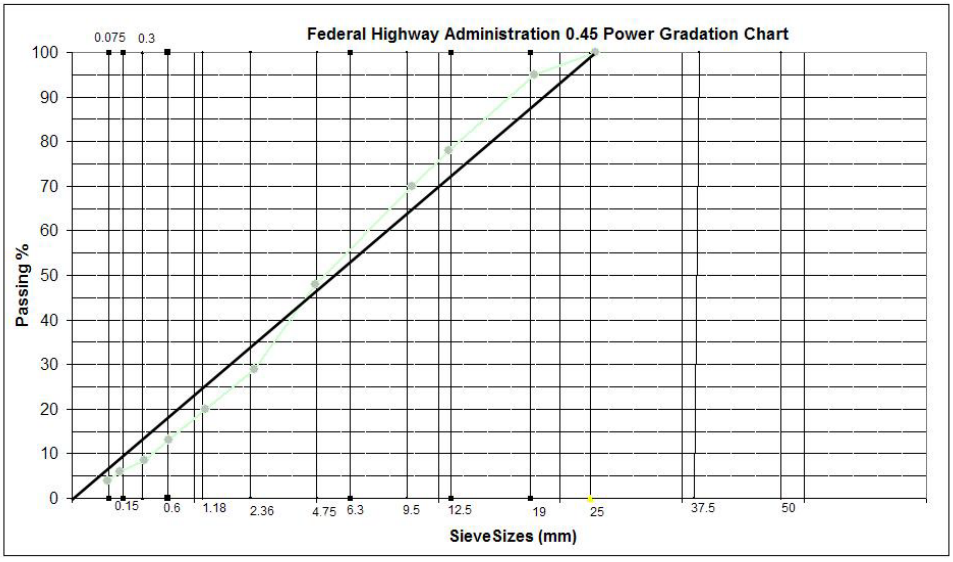
Sieve Size (mm)	PASSING (%)	SA Factor m^2/kg	SA m^2/kg
37.5			
25			
19			
12.5			
9.5		0.41	0.41
4.75	**50**	0.41	0.205
2.36	36	0.82	0.295
1.18	**26.5**	1.64	0.435
0.6	20	2.87	0.574
0.3	**12**	6.14	0.737
0.15	8.5	12.29	1.045
0.075	5	32.77	1.639
TOTAL SURFACE AREA (m^2/kg)			5.339
Assumed SA			4.00

CONSTANTS
VARIABLES
CALCULATED

Fig. 10

PROCEDURE FOR SELECTION OF INITIAL GRADATION

ASTM D 3515						CRITERIA AS PER BAILEY METHOD		SPECIFIED
Sieve Size (mm)	MDL	Specs		Mid Point	Tolerance			
						C/A Ratio = (%Passing Half Sieve-% Passing PCS) / (100-Passing Half Sieve)	0.73	0.70 ~ 0.85
25	100.0	100	100	100.0		Max. Size		
19	88.4	90	100	95.0	7±	NMPS		
12.5	73.2	65	85	78.0		FA_c Ratio = % passing SCS / % passing PCS	0.42	0.35 ~ 0.50
9.5	64.7	56	80	70.0		Half Sieve		
4.75	47.4	35	65	48.0		PCS		
2.36	34.6	23	49	29.0				
1.18	25.3	16	37	20.0		SCS		
0.6	18.7	11	29	13.0	4±	FA_f Ratio = % passing TCS / % passing SCS	0.43	0.35 ~0.50
0.3	13.7	5	19	8.5		TCS		
0.15	10.0	4	13	6.0				
0.075	7.3	2	8	4.0	1±			



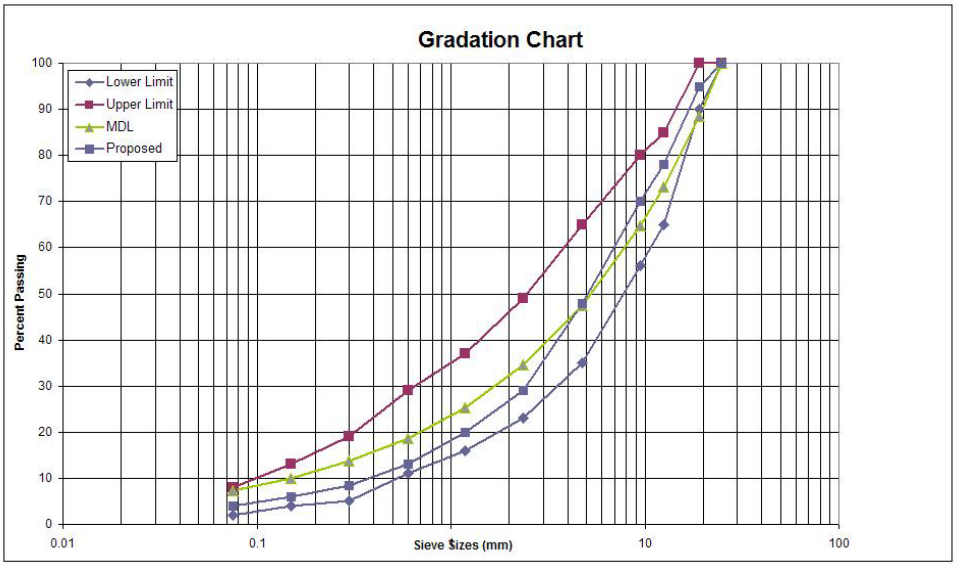


Fig. 11

NATIONAL ENGINEERING SERVICES
PAKISTAN (Pvt) LIMITED.

WORKSHEET FOR HOT MIX ASPHALT (25mm)

PROJECT:

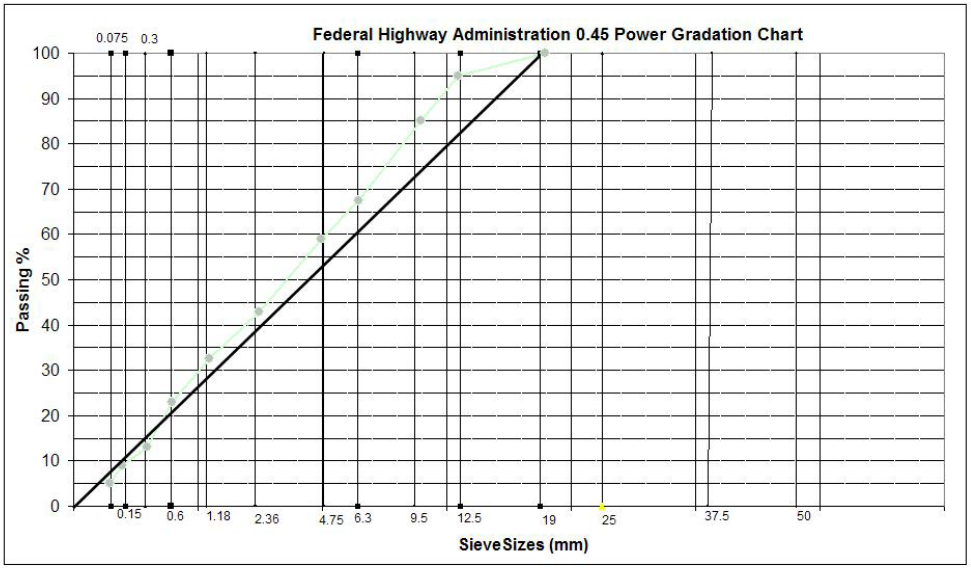
DATE:

MATERIAL		**ASTM D 3515**				**Proposed**			
Specific Gravity of Bitumen	**Gb**		1.03			**Sieve Analysis and Determination of Surface Area of Total Aggregates by Edwards-Hveem Method**			
Apparent Specific Gravity of Aggregates	**Gsa**		2.735						
Bulk Specific Gravity of Aggregates	**Gsb**		2.700			Sieve Size	PASSING	SA Factor	SA
Effective Specific Gravity of Aggregates	**Gse**	Gsb+F(Gsa-Gsb)	2.728			(mm)	(%)	m^2/kg	m^2/kg
Factor	**F**		0.8			37.5			
Surface Area of Aggregates	**SA** (m^2/kg)		4.444			25			
Average Film Thickness of Asphalt	**T_F (microns)**		8			19			
Wt. of Effective Asphalt/Unit wt. of Agg.	**Wbe**	(SA)*(T_F*10^{-6})*(Gb*1000)	0.0366			12.5			
Mass of Aggregates	**Ws** (kg)		1			9.5		0.41	0.41
Percent Asphalt Absorbed	**Pba** (%)	((Gse-Gsb)/(Gse*Gsb))*Gb*100	0.392	0.003915		4.75	**48**	0.41	0.197
Wt. of Absorbed Asphalt	**Wba** (kg)	Pba*Ws	0.392	0.003915		2.36	29	0.82	0.238
Wt. of Total Asphalt	**Wb**	Wbe+Wba	0.428	0.0405		1.18	**20**	1.64	0.328
Volume of Absorbed Asphalt	**Vba**	Wba/Gb	0.380	0.003801		0.6	13	2.87	0.373
Volume of effective Asphalt	**Vbe**	Wbe/Gb	0.036	0.035548		0.3	**8.5**	6.14	0.522
Total Volume of Asphalt	**Vb**	Vba+Vbe	0.416	0.039349		0.15	6	12.29	0.737
Weight of Mix	**Wm**	Ws+Wb	1.428	1.0405		0.075	5	32.77	1.639
Total Asphalt Content	**Pb (%)**	Wb/Wm	0.300	0.038951	**3.90**	**TOTAL SURFACE AREA (m^2/kg)**			**4.444**
Effective Asphalt Content	**Pbe (%)**	Wbe/Wm	0.026	0.035188	**3.52**	Assumed SA			4.00
Bulk Volume of Aggregates	**Vsb (M^3)**	Ws/Gsb	0.370	0.37037					
Total Volume of Mix (Voidless Mix)	**Vmm (M^3)**	Vbe+Vsb	0.406	0.405918		**CONSTANTS**			
Bulk Volume of Mix	**Vmb (M^3)**	(Vsb+Vbe)/1-Pa	0.427	0.427282		**VARIABLES**			
Percent Air Voids	**Pa (%)**		5			**CALCULATED**			
Voids in Total Mix	**VTM (%)**	((Vmb-Vmm)/Vmb)*100	**5**	**5**					
Voids in Mineral Aggregates	**VMA (%)**	((Vmb-Vsb)/Vmb)*100	**13.32**	**13.32**	**13**				
Voids Filled with Asphalt	**VFA (%)**	((VMA-VTM)/VMA)*100	**62.46**	**62.46**					
Filler Asphalt Ratio	**F/A**	P_{200}/Pbe	128.37	**1.28**					

Fig. 12

PROCEDURE FOR SELECTION OF INITIAL GRADATION

ASTM D 3515						CRITERIA AS PER BAILEY METHOD		SPECIFIED
Sieve Size (mm)	MDL	Specs		Mid Point	Tolerance			
						C/A Ratio = (%Passing Half Sieve-% Passing PCS) / (100-Passing Half Sieve)	0.75	0.70 ~ 0.85
19	100.0	100	100	100.0		Max. Size		
12.5	82.8	90	100	95.0	7±	NMPS		
9.5	73.2	77	93	85.0		FA_c Ratio = % passing SCS / % passing PCS	0.53	0.35 ~ 0.50
6.25	60.6	55	80	67.5		Half Sieve		
4.75	53.6	44	74	59.0				
2.36	39.1	28	58	43.0		PCS		
1.18	28.6	20	45	32.5		FA_f Ratio = % passing TCS / % passing SCS	0.39	0.35 ~0.50
0.6	21.1	13	33	23.0	4±	SCS		
0.3	15.5	5	21	13.0				
0.15	11.3	4	14	9.0		TCS		
0.075	8.3	2	8	5.0	1±			



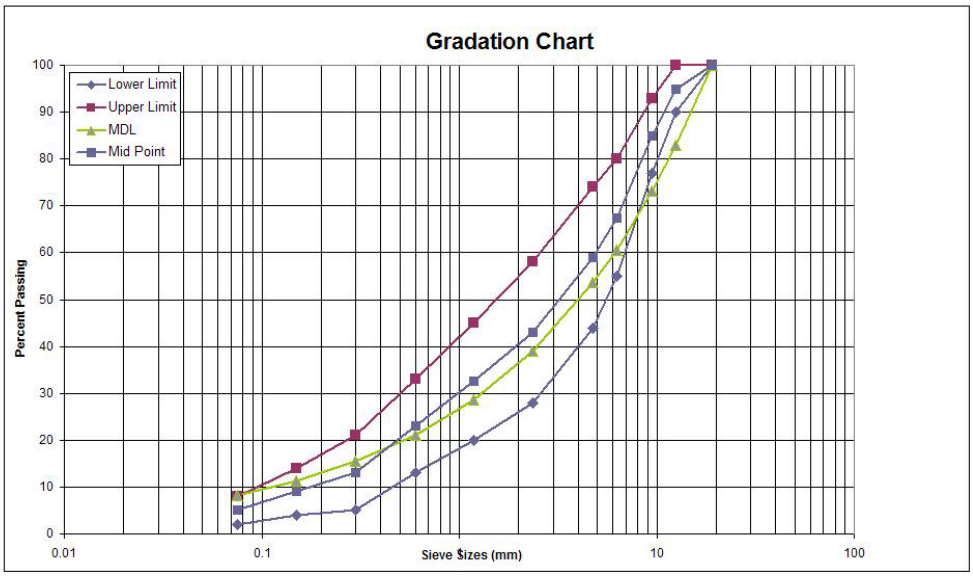


Fig. 13

NATIONAL ENGINEERING SERVICES
PAKISTAN (Pvt) LIMITED.

WORKSHEET FOR HOT MIX ASPHALT (19 mm)

PROJECT:

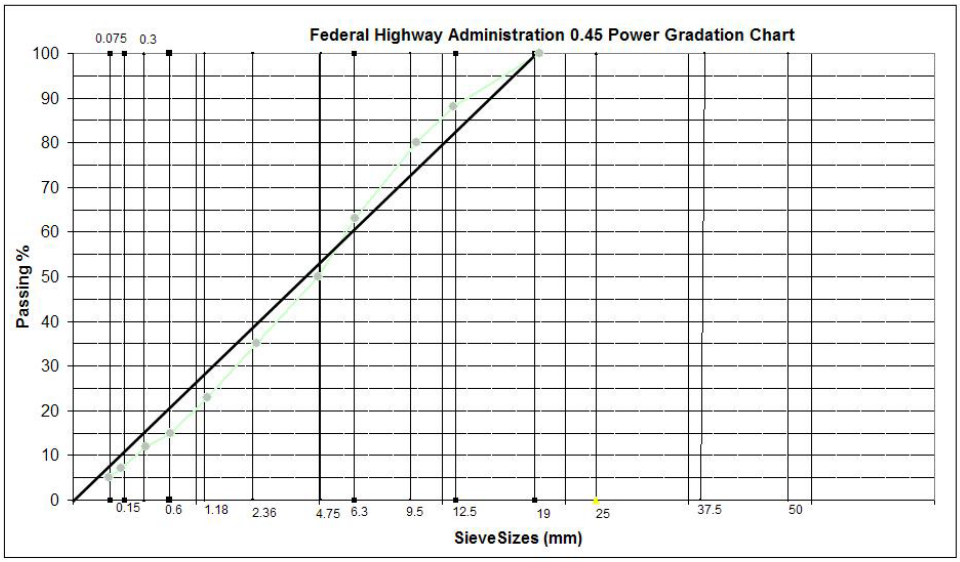
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MATERIAL		ASTM D 3515				Mid Point			
Specific Gravity of Bitumen	Gb		1.03			Sieve Analysis and Determination of Surface Area of Total Aggregates by Edwards-Hveem Method			
Apparent Specific Gravity of Aggregates	Gsa		2.735						
Bulk Specific Gravity of Aggregates	Gsb		2.700			Sieve Size	PASSING	SA Factor	SA
Effective Specific Gravity of Aggregates	Gse	Gsb+F(Gsa-Gsb)	2.728			(mm)	(%)	m^2/kg	m^2/kg
Factor	F		0.8			37.5			
Surface Area of Aggregates	SA (m^2/kg)		5.740			25			
Average Film Thickness of Asphalt	T_F (microns)		8			19			
Wt. of Effective Asphalt/Unit wt. of Agg.	Wbe	(SA)*(T_F*10^{-6})*(Gb*1000)	0.0473			12.5			
Mass of Aggregates	Ws (kg)		1			9.5		0.41	0.41
Percent Asphalt Absorbed	Pba (%)	((Gse-Gsb)/(Gse*Gsb))*Gb*100	0.392	0.00392		4.75	**59**	0.41	0.242
Wt. of Absorbed Asphalt	Wba (kg)	Pba*Ws	0.392	0.00392		2.36	43	0.82	0.353
Wt. of Total Asphalt	Wb	Wbe+Wba	0.439	0.05122		1.18	**32.5**	1.64	0.533
Volume of Absorbed Asphalt	Vba	Wba/Gb	0.380	0.00380		0.6	23	2.87	0.660
Volume of effective Asphalt	Vbe	Wbe/Gb	0.046	0.04592		0.3	**13**	6.14	0.798
Total Volume of Asphalt	Vb	Vba+Vbe	0.426	0.04972		0.15	9	12.29	1.106
Weight of Mix	Wm	Ws+Wb	1.439	1.05122		0.075	5	32.77	1.639
Total Asphalt Content	Pb (%)	Wb/Wm	0.305	0.04872	**4.87**	TOTAL SURFACE AREA (m^2/kg)			**5.740**
Effective Asphalt Content	Pbe (%)	Wbe/Wm	0.033	0.04500	**4.50**	Assumed SA			4.00
Bulk Volume of Aggregates	Vsb (M^3)	Ws/Gsb	0.370	0.37037					
Total Volume of Mix (Voidless Mix)	Vmm (M^3)	Vbe+Vsb	0.416	0.41629		CONSTANTS			
Bulk Volume of Mix	Vmb (M^3)	(Vsb+Vbe)/1-Pa	0.434	0.43364		VARIABLES			
Percent Air Voids	Pa (%)		4			CALCULATED			
Voids in Total Mix	VTM (%)	((Vmb-Vmm)/Vmb)*100	**4**	**4**					
Voids in Mineral Aggregates	VMA (%)	((Vmb-Vsb)/Vmb)*100	**14.59**	**14.59**	**13**				
Voids Filled with Asphalt	VFA (%)	((VMA-VTM)/VMA)*100	**72.58**	**72.58**					
Filler Asphalt Ratio	F/A	P_{200}/Pbe	102.62	**1.03**					

Fig. 14

PROCEDURE FOR SELECTION OF INITIAL GRADATION

ASTM D 3515						CRITERIA AS PER BAILEY METHOD		SPECIFIED
Sieve Size (mm)	MDL	Specs		Mid Point	Tolerance			
						C/A Ratio = (%Passing Half Sieve-% Passing PCS) / (100-Passing Half Sieve)	0.76	0.70 ~ 0.85
19	100.0	100	100	100.0		Max. Size		
12.5	82.8	90	100	88.0	7±	NMPS		
9.5	73.2	77	93	80.0		FA_c Ratio = % passing SCS / % passing PCS	0.43	0.35 ~ 0.50
6.25	60.6	55	80	63.0		Half Sieve		
4.75	53.6	44	74	50.0				
2.36	39.1	28	58	35.0		PCS		
1.18	28.6	20	45	23.0		FA_f Ratio = % passing TCS / % passing SCS	0.47	0.35 ~0.50
0.6	21.1	13	33	15.0	4±	SCS		
0.3	15.5	5	21	12.0				
0.15	11.3	4	14	7.0		TCS		
0.075	8.3	2	8	5.0	1±			



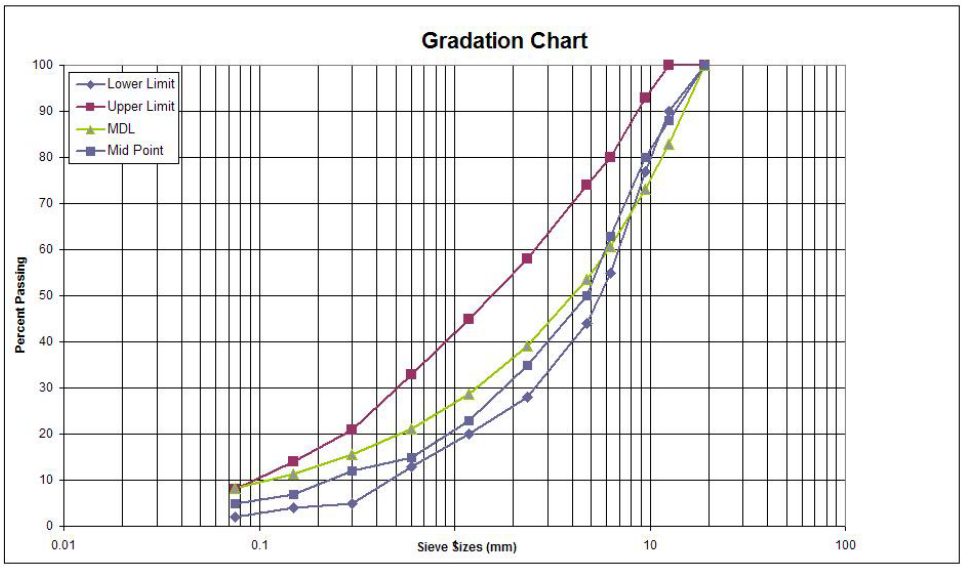


Fig. 15

NATIONAL ENGINEERING SERVICES
PAKISTAN (Pvt) LIMITED.

WORKSHEET FOR HOT MIX ASPHALT (19 mm)

PROJECT:

DATE:

MATERIAL		**ASTM D 3515**				**Proposed**			
Specific Gravity of Bitumen	**Gb**		1.03			**Sieve Analysis and Determination of Surface Area of Total Aggregates by Edwards-Hveem Method**			
Apparent Specific Gravity of Aggregates	**Gsa**		2.735						
Bulk Specific Gravity of Aggregates	**Gsb**		2.700			Sieve Size	PASSING	SA Factor	SA
Effective Specific Gravity of Aggregates	**Gse**	Gsb+F(Gsa-Gsb)	2.728			(mm)	(%)	m^2/kg	m^2/kg
Factor	**F**		0.8			37.5			
Surface Area of Aggregates	**SA** (m^2/kg)		4.945			25			
Average Film Thickness of Asphalt	**T_F (microns)**		8.5			19			
Wt. of Effective Asphalt/Unit wt. of Agg.	**Wbe**	(SA)*(T_F*10^{-6})*(Gb*1000)	0.0433			12.5			
Mass of Aggregates	**Ws** (kg)		1			9.5		0.41	0.41
Percent Asphalt Absorbed	**Pba** (%)	((Gse-Gsb)/(Gse*Gsb))*Gb*100	0.392	0.00392		4.75	**50**	0.41	0.205
Wt. of Absorbed Asphalt	**Wba** (kg)	Pba*Ws	0.392	0.00392		2.36	35	0.82	0.287
Wt. of Total Asphalt	**Wb**	Wbe+Wba	0.435	0.04721		1.18	**23**	1.64	0.377
Volume of Absorbed Asphalt	**Vba**	Wba/Gb	0.380	0.00380		0.6	15	2.87	0.431
Volume of effective Asphalt	**Vbe**	Wbe/Gb	0.042	0.04204		0.3	**12**	6.14	0.737
Total Volume of Asphalt	**Vb**	Vba+Vbe	0.422	0.04584		0.15	7	12.29	0.860
Weight of Mix	**Wm**	Ws+Wb	1.435	1.04721		0.075	5	32.77	1.639
Total Asphalt Content	**Pb (%)**	Wb/Wm	0.303	0.04508	**4.51**	**TOTAL SURFACE AREA (m^2/kg)**			**4.945**
Effective Asphalt Content	**Pbe (%)**	Wbe/Wm	0.030	0.04134	**4.13**	Assumed SA			4.00
Bulk Volume of Aggregates	**Vsb (M^3)**	Ws/Gsb	0.370	0.37037					
Total Volume of Mix (Voidless Mix)	**Vmm (M^3)**	Vbe+Vsb	0.412	0.41241		**CONSTANTS**			
Bulk Volume of Mix	**Vmb (M^3)**	(Vsb+Vbe)/1-Pa	0.430	0.42959		**VARIABLES**			
Percent Air Voids	**Pa (%)**		4			**CALCULATED**			
Voids in Total Mix	**VTM (%)**	((Vmb-Vmm)/Vmb)*100	**4**	**4**					
Voids in Mineral Aggregates	**VMA (%)**	((Vmb-Vsb)/Vmb)*100	**13.78**	**13.78**	**13**				
Voids Filled with Asphalt	**VFA (%)**	((VMA-VTM)/VMA)*100	**70.98**	**70.98**					
Filler Asphalt Ratio	**F/A**	P_{200}/Pbe	110.91	**1.11**					

Fig. 16