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Effect of Aggregate Gradation Variation on the Marshall Mix Properties of Asphalt Concrete

Rajendra Maharjan [a], Gautam Bir Singh Tamrakar [b]

[a, b] *Department of Civil Engineering, Pulchowk Campus, IOE, TU, Nepal*
Corresponding Email: [a] m.01rajendra@gmail.com, [b] gbstamrakar@hotmail.com

Abstract

Mineral aggregate covers 90 to 96% of Asphalt Concrete mix by weight or approximately 75 to 85% by volume. It has a significant effect towards resisting the different external loads and environmental condition. Gradation is one of the important characteristics of aggregates affecting permanent deformation of hot mix asphalt. Hence, is important to analyze that how the variation in aggregate gradation within the specified limits can affect the essential mix design properties of bituminous mix.

In the study, optimum bitumen content is produced for different 6 gradations. 5 gradations were taken between the limits and one above the limits. Optimum Bitumen Content increases from coarser to finer gradation. Considering the OBC, stability and density, for the higher strength, we should work between the middle and upper gradation of limit provided by specification. A maximum stability of 1550 kg was observed at OBC of 5.37% at upper grading. At OBC, a maximum density of 2407 kg/m^3 was observed at upper grading.

Keywords

Gradation – Marshall Stability – Flow Value – Density – Aggregates – Gradation limits – OBC

1. Background

Majority of roads in Nepal are flexible pavements having primarily bitumen based macadamized roads with a thin bituminous surfacing or a premix carpet as a wearing course and Asphalt Concrete (AC) is widely used bituminous material from many years for construction of flexible pavements. Asphalt Concrete is the dense graded premixed bituminous mixture consisting of carefully proportioned mixture of coarse aggregate, fine aggregate, mineral filler and bitumen. Coarse and Fine aggregate acts as the structural skeleton of the pavements while bitumen function as glue for the mixture. When properly designed with appropriate proportion of ingredients, it will provide a surfacing of exceptional durable and capable in carrying the heaviest traffic. An asphalt concrete surface will generally be constructed for high-volume primary highways having an average annual daily traffic load greater than 1200 vehicles per day. It is the highest quality of construction among the group of black top pavements.

The particle size distribution, or gradation, of aggregates is most important factor that affects the whole performance of the pavement material. Gradation is one of most influencing factors for Marshall Properties of Asphalt Concrete mix, so it is required to select a best aggregates gradation. The best gradation is that gradation of aggregates which gives the highest density. When fine particles are properly packed between coarser particles, which reduces the voids space between particles is called as Best gradation.

In the present study, five gradation, Upper Grade, Middle Grade, Lower grade, Grade A (with more middle size particle) and Grade B (with less middle size particles) were used within the range specified by the Standard Specification for Road and Bridge Work, 2073 (SSRBW, DOR)[1] and a super grade (higher than upper limit of SSRBW, DOR)were used at 4 %, 4.5 %, 5 %, 5.5%, 6% & 6.5% bitumen content. Marshall Mixes were prepared and tested for its properties.

1.1 Research Objectives

Aggregate presents major portion of asphalt concrete. It was found that researchers have come to different conclusions with regard to the effect of aggregate gradation on Marshall Properties of asphalt mixtures. The main objectives of this research are:

1. To evaluate the effect of the aggregate gradation variation on the Marshall Mix Properties of the Asphalt Concrete.
2. To find the gradation range at which the Asphalt concrete attains the higher strength at OBC.
3. To examine whether it is possible or not to wide our aggregate gradation range given by DOR.
4. To find out the optimum binder content for different grade aggregate Asphalt mixtures.

1.2 Assumptions and Limitations

The Assumptions and Limitations of the study are as follows:

1. There are the several factors that influence the properties of the Asphalt Concrete. The work done herein is concentrated only in the effect of the aggregate gradation variation on asphalt Concrete.
2. Aggregates were collected from the single source i.e. Mahadevbesi
3. Here we assumed that for the other source aggregates, numerical value of the strength may be different but their strength varying pattern for different grading will be same. But this may not remain same.
4. All the results were drawn as per the Marshall Test only. It may be different if other tests were carried.

2. Literature Review

The structural strength of asphaltic concretes and coated macadam relies primarily on the friction, and mechanical interlock between aggregate particles. The addition of a binding agent to the gradation, such as bitumen, provides a lubricant which enables the material to become workable, allowing ease of compaction, and contributes to the final mixture properties. The quantity of binder introduced to the gradation is critical, as too much, or too little will adversely affect the mixture properties, but it must be realized that similar consequences may result from variations in the aggregate grading. The development of aggregate grading for use in road base materials has been empirical throughout practice in the United Kingdom, resulting in the envelopes currently specified in BS 4987[2]. These grading forms very dense matrices of stone particles, and are analogous to the type of gradations which have been developed for asphaltic concretes in the United States of America. The grading used in asphaltic concretes was developed through a philosophy which aimed to maximize the density of the mineral aggregate, and is based upon a gradation curve suggested by Fuller and Thomson in 1907 [3].

Stakston and Bahia [4] have indicated that rut resistance is “highly dependent on aggregate grading”, and that mixes made with the best possible materials would fail without a proper gradation. P. Sarika et al. [5] reported that MORTH lower gradation trial present the best result compared to the upper and middle gradations trials and the Superpave gradation can be considered as more economical than the MORTH gradation due less binder content consumption and more stability. Mohamed Ilyas Anjum [6] obtained Marshall Test properties fall within the MORTH specifications for both SDBC and BC mixes at mid point gradation, with flow values exceeding the limit. Afaf A.H.M. [7] reported that course gradation of asphalt mixture design gives superior results against flow while fine gradation has the highest amount of deformation. Arijit Kumar Banerji et al. [8] reported that variation in aggregate gradation within the specified limits can affect the essential mix design properties of bituminous mix.

Amir Golalipour et al [9]divided the gradation limit into three band, upper, middle and lower band and in order to compare each of the variation, the medium gradation of each variation were chosen from sieve diagram. The gradation limit they used was more or less similar to the limit as specified by DOR of Nepal. Their research showed that upper gradation band (finer grading) gives the good performance against the rutting. The upper band aggregate showed the high stability value and also less permanent deformation. Manal A. Ahamed et al [10][22] collected the three type of aggregate namely basalt, dolomite & limestone. They used the four gradations (according to Egyptian Specification), coarse, fine, open & dense gradation. By performing the experiment they showed that coarser grading gives the good performance against the rutting & permanent deformation is also less for coarse grading. Dipesh Kumar Singh et al [11]divided the gradation limit into five grading line and their research showed that the stability value is higher at the coarser grading.

Therefore, this study focuses on the effect of aggregate gradation more in detail and investigates the effect of coarse and fine gradation on Marshall Properties by dividing the gradation limits into different parts and studies were carried out.

3. Methodology

3.1 Material Selection

3.1.1 Bitumen

In this study, the grade of bitumen used is of Penetration Grade 80/100 which is generally used in Kathmandu / Nepal. Bitumen properties were evaluated by the standard laboratory tests which are demonstrated in the table 1 and were verified according to IS 73:2013: Indian Standard: Paving Bitumen Specification [12].

3.1.2 Aggregate

To prepare the bituminous mix specimens crushed coarse aggregate, fine aggregate and mineral filler were brought from a Mahadevbesi quarry, Dhading located near the Kathmandu Valley. Initially, the physical properties of aggregates were evaluated and verified according to Standard Specification for Road and Bridge Works, 2070 (SSRBW, DOR) of Nepal and are shown in Table 2. From the test results, it was found that the properties of aggregates are within the specified limits.

Other specific gravity characteristics of the aggregates are in table 3

3.1.3 Gradation

In this study, six gradation of the aggregate were chosen, the upper grade and lower grade were the gradation limit given by DOR, other five gradation chosen were the middle grade (between upper and lower limit), Grade A (medium size particle more), Grade B (medium size particle less)and Super Grade (higher than the upper limit). One objective of this study is to check the possibility of widening the gradation range. Here gradation range was widened from lower limit to over upper limit i.e. up to super gradation. The percentage of passing and particle size distribution curve for each grading under this study is shown in the Table 4 and Figure 1 & 2 below.

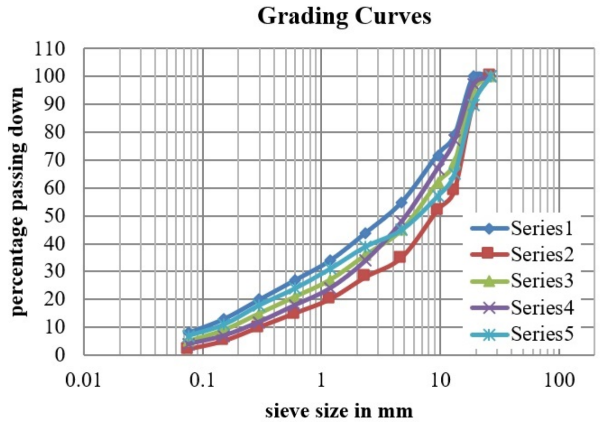

Figure 1: Series 1: Upper Grade 2: Lower Grade 3: Middle Grade 4: Grade A 5: Grade B

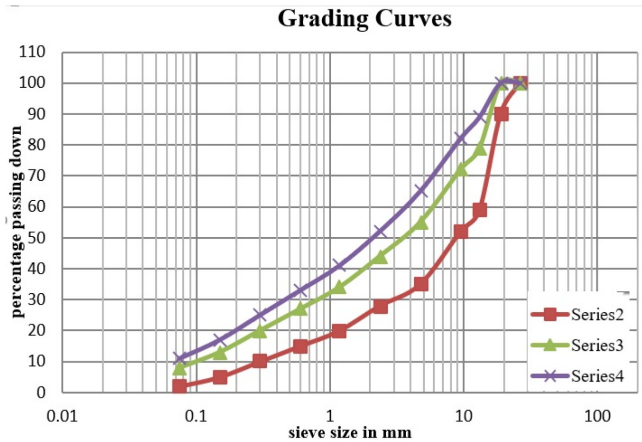

Figure 2: Series 2: Lower Grade 3: Upper Grade 4: Super Grade

3.1.4 filler Material

In this study stone dust was used as filler. The test for the specific gravity of the filler was performed and the results are shown below.

Apparent Specific Gravity of filler: 2.563

3.1.5 Marshall tests

3 Marshall specimens were prepared for each samples types. All together 108 samples were prepared to justify

Table 1: Bitumen Properties

S. N.	Description of Test	Test Value	Method of Test
1	Penetration at 25^{o}C, 100 g, 5 s, 0.1 mm	91	IS 1203
2	Absolute viscosity at 60 ^{o}, Poises	1192.35	IS 1206 part 2
3	Kinematic viscosity at 135 ^{o}, cSt	276	IS 1206 part 3
4	Softening point (R & B) ^{o},	42	IS 1205
5	Ductility at 25 ^{o}, cm	Not Break	IS 1208
6	Specific gravity	1.018	IS 1202
7	Loss on heating, Percent	0.69	IS 1207
8	Solubility in trichloroethylene, Percent	100	IS 1216

Table 2: Physical Requirements for Coarse Aggregate and their Results

Test	Specification	Result	Method of Test
Los Angeles Abrasion Value	Maximum 30 %	30.97%	IS 2386 part 4
Aggregate Impact Value	Maximum 24 %	20.23%	IS 2386 part 4
Aggregate Crushing Value		26.08%	IS 2386 part 4
Flakiness Index	Maximum 35 %	20.33%	IS 2386 part 1
Sodium Sulphate Soundness	Maximum 12 %	0.58%	IS 2386 part 5

Table 3: Specific Gravity test results of Aggregates

Types of Aggregates	Water Absorption %	Apparent Sp. Gr.	Bulk Sp. Gr.
Coarse (26.5 - 10 mm)	0.727	2.737	2.684
Coarse (10 - 4.75 mm)	0.936	2.709	2.642
Fine (4.75 - .075 mm)		2.687	

the effects of gradation in Asphalt concrete. Optimum bitumen content and the properties of the asphalt concrete for each gradation was calculated based on these samples to conclude.

4. Results and Discussion

According to SSRBW, DOR minimum Stability for Asphalt Concrete pavements is 9 KN at 60 ^{o}C. The stability values for all six gradations are higher than that of minimum value prescribed in guidelines except for lower grade at 6 and 6.5% bitumen content and for the middle grade at 6.5% bitumen content that indicates the importance of the optimum bitumen content. In this

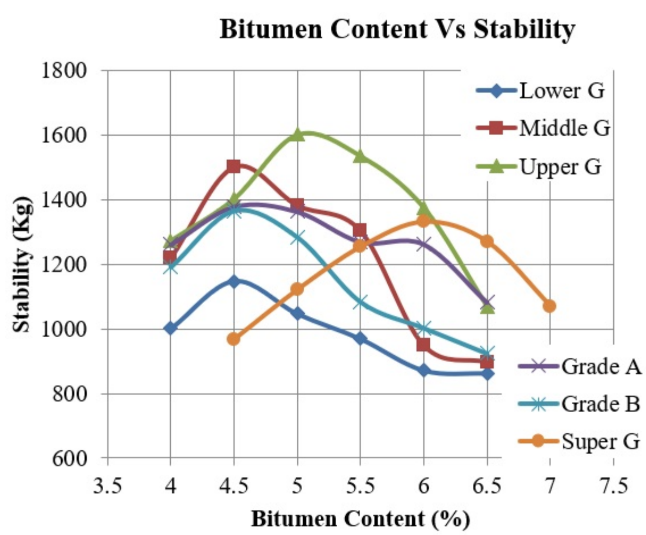

Figure 3: Variation of Stability at different Bitumen Content for different gradation

study it is observed that when bitumen percent is increased, stability also increases up to certain point, after increment of bitumen percent it again decreases. Stability value is highest in Upper Grade at 5% bitumen content. The variation of the stability obtained for

Table 4: Percentage Passing for each Grading

Sieve Size (mm)	Cumulative % by weight of the total aggregate passing					
	Upper Limit	Lower Limit	Middle Grade	Grade A	Grade B	Super Grade
26.5	100	100	100	100	100	100
19	100	90	95	97	90	100
13.2	79	59	69	77	65	89
9.5	72	52	62	67	57	82
4.75	55	35	45	48	45	65
2.36	44	28	36	34	39	52
1.18	34	20	27	24	31	41
0.6	27	15	21	18	24	33
0.3	20	10	15	12	18	25
0.15	13	5	9	7	11	17
0.075	8	2	5	4	7	11

various grading and different bitumen content are shown in Figure 3.

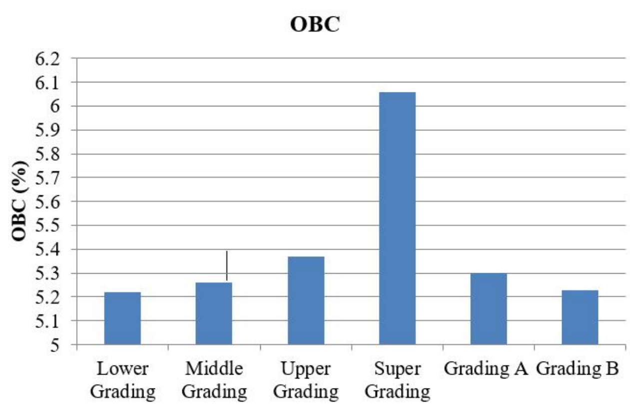

Figure 4: All Gradation Vs OBC Variations

For each gradation of aggregate, Marshall Test specimens were prepared at different bitumen content to study the effect of aggregate gradation on the Marshall properties of AC mix. The Optimum Bitumen Content (OBC), and other properties such as Stability, Bulk Density, Flow, and Air voids obtained at OBC were plotted against respective gradations shown in Table 5 and Figures 5, 6, 7, 8 and 9. The optimum bitumen content is increasing when we observe upper gradation. This is because of increased surface area due to presence of finer materials (finer gradation). The upper

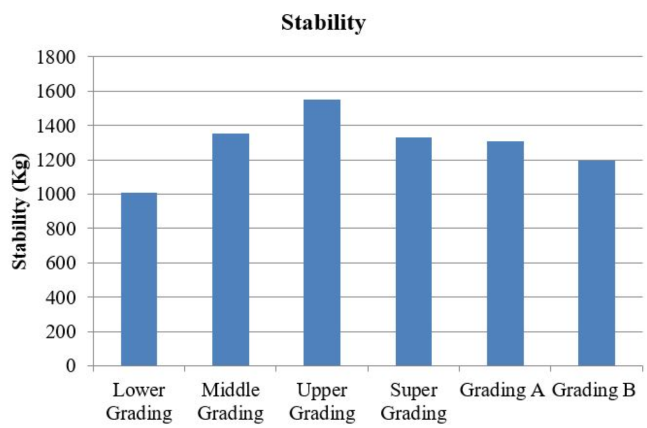

Figure 5: All Gradation Vs Stability Variations

gradation, of the limit of the specification, shows the highest stability, highest unit weight and corresponding lowest air void content among all the mixes at OBC. Flow Values are decreasing from lower to upper grade but increases from upper to super. The density is increasing from lower to upper grade and then decreases at OBC. So the higher density is achieved within the middle and upper grade.

Table 5: Marshall Properties of Asphalt Concrete

	Optimum Bitumen Content	Stability at OBC	Flow at OBC	Density at OBC	VTM at OBC	VMA at OBC
	(%)	(Kg)	(mm)	(kg / m^3)	(%)	(%)
Lower Grading	5.22	1007	3.36	2396	3.8	16.21
Middle Grading	5.26	1355	3.3	2400	3.5	16.05
Upper Grading	5.37	1550	2.65	2407	2.8	15.63
Grading A (Mi P M)	5.3	1305	2.5	2390	3.7	16.26
Grading B (Mi P L)	5.23	1195	2.9	2393	3.8	16.1
Super Grading	6.06	1330	3.4	2395	2.78	15.74

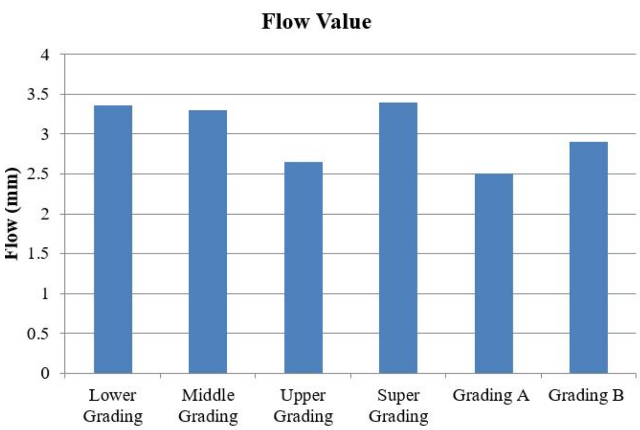

Figure 6: All Gradation Vs Flow Variations

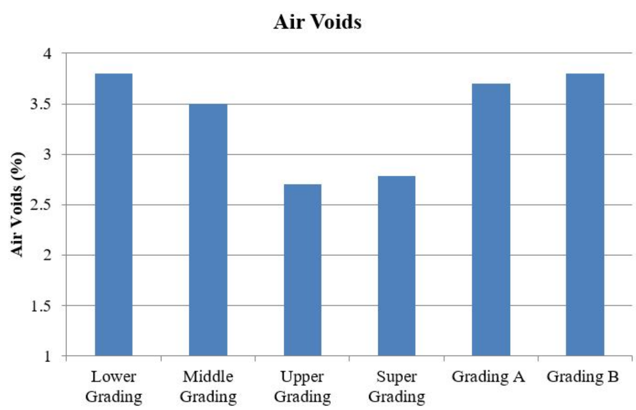

Figure 8: All Gradation Vs Air Voids Variations

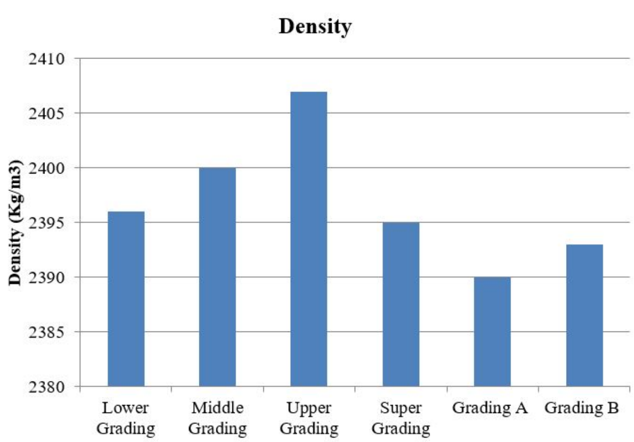

Figure 7: All Gradation Vs Density Variations

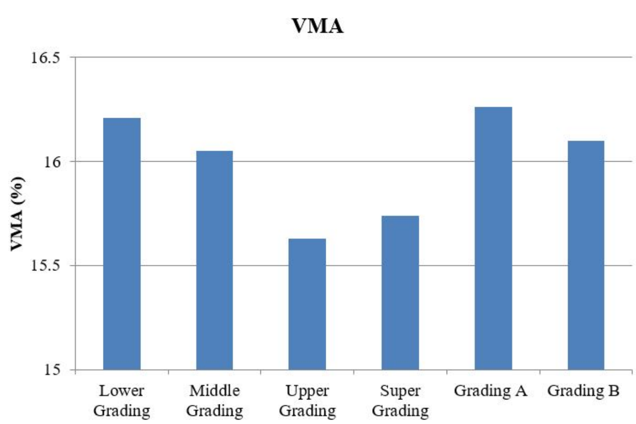

Figure 9: All Gradation Vs Voids in Mineral Aggregate

5. Conclusion

Based on the various laboratory test following results are concluded.

- OBC is minimum for the lower grade and maximum for the super grade i.e. OBC is increasing from lower to upper grade within the gradation range given by DoR. So lower gradation limit is more economical in terms of bitumen content.
- Since OBC increases from lower to upper grade, it can be concluded that finer grading consumes more bitumen than that of the coarse grading.
- Stability is highest at the upper grade and lowest at the lower grade i.e. stability is increasing from lower to upper grade and decreasing from upper to super grade. Hence, to get the high stability we should work at upper grade but practically it is very difficult. Stability between the upper and super grade is also considerable but density decreases considerably from upper to super grade. Stability and density both good within the middle and upper grade. So for the higher strength we can work between the middle and upper grade.
- Here the stability up to super grade is also considerable. So we can use the new gradation range from lower grade to super grade. However, OBC is increasing considerably from upper to super grade that increases the cost of construction. So it is suggested that as far as possible we should manage the aggregate gradation between the limit as given by DOR and if it is not possible we should manage the grading between lower and super range instead of using the natural sand.
- It can be concluded that among these four parallel grading (lower, middle, upper and super), upper gradation is the best one and then middle gradation, after that super gradation and lower grading is the last one in terms of the Marshall Properties.

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