Gradation effects on hot mix asphalt

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Abstract*: Well gradation in hot mix asphalt (HMA) is as important as in soil. It is measured in density of a material and is the interlocking of particles. The strength of these particulate masses is dependent on it. If the material is strong enough but its gradation is poor, slippage over amongst the particles occurs leading to settlement and compression which is criterion for failure if limit is exceeded. In flexible pavements, this settlement in riding surface or wearing course occurs which is called rutting, a permanent or plastic deformation of HMA of poor gradation. An HMA generally consists of 85% to 90 % of coarse aggregates and sand; the rest being filler, binder and air. In this study, effect of gradation – variations of aggregates is focused to measure its strength in terms of Marshall Stability and wheel tracking test measuring the amount of or depth of ruts, a newly developed apparatus. Five gradations of the aggregates are considered and tested in the laboratory for the two mentioned tests in addition to other routine tests on aggregate, binder / bitumen. Results show that one of the five gradations, proves to be strongest; giving highest Marshal Strength of 1420kg, the lowest flow of 8.3 mm and the lowest rut depth 5.4 mm as compared to the one giving maximum of 17.5 mm under 5tons wheel load with 12000 number of passes with a frequency of 50 passes / min.

Keywords: Pavement rut, gradation effect, asphalt concrete course, Marshal Stability. Wheel tracking

I. INTRODUCTION

For the development of country, movement of goods from one place to other is very important for the community to survive and progress. Road networks, one of the transportation means, are constructed for this purpose. The roads of these must be constructed according to well defined engineering principles. George and Waheed [1] say that the objective of pavement design is to provide a structural and economical combination of engineering materials to carry traffic in a given climate over the existing soil conditions for a specified period. Our country being a developing one, road networks are in a boom. Expressways, motorways are joining far flung areas bringing to them prosperity. The function of roads is like veins of blood in human body. Wherever it passes, development occurs over there.

The living example of business strides and growth of peoples prosperity due to the construction of highways is the construction of motorways and expressways in Pakistan. In Peshawar, ring road is the best example where people use to fear in jungles but now developments of housing colonies, markets, shops on both sides of it has given boost to life. The land which was very cheap before costs more than Rs. Ten lacs per Marla. Universities and other business centres opened up and the hustle and bustle of life can be seen in these areas .The advantage of these roads can be taken if properly designed, constructed and maintained.

According to NHA [2] statistics, about 263774km of roads have been constructed as a flexible pavements. Unfortunately many show signs of failure as far as its serviceability in the form of smooth ride in concerned. This is due to development of permanent compression in the top surface know as wearing surface or asphaltic concrete course of the pavement. Other failures are fatigue and thermal cracking, stripping and many more.

With the advent of 22 wheelers / trawlers, the roads designed for light loads are giving in to these heavy wheel loads. Rutting is the main phenomenon that occurs in most of the roads. This makes the unridrivable surface prone to accident and accumulation of water in ruts that ultimately damage the lower parts of the roads. The general schematics of rutting can be seen by figure 1.1.

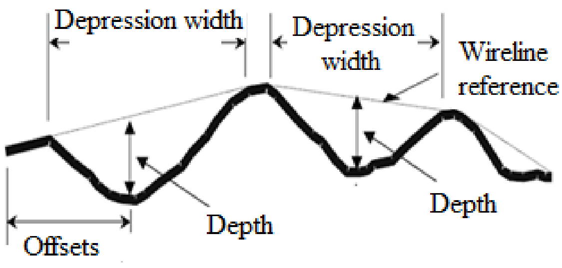

Figure 1.1: Schematic diagram of ruts in pavement.

Rutting is measured in depth and a wearing surface is considered to have failed if it experiences a rut depth of

2cm... When developed in wearing surface of a pavement, these ruts go parallel with the road in series form as can be seen in figure 1.1. They also become pond of water due to bitumen cracks and allowing water to seep into the lower layers of the pavement as seen in figure 1.2. This water reaches the natural soil known as subgrade that gets weaker and aggravating the problem.

Figure 1.2: Developed ruts in HMA Course.

So, the aim of this study is to investigate into such a gradation of asphalt mix so that highest strength is resulted. This strength is envisaged to be determined from a common test known as Marshall Stability test. The rut resistance will be measured by wheel tracker test. Different gradations of gravels, sand, fines and filler materials along with bitumen will be prepared for this purpose and tested. So the purpose of this study is to:

a. Investigate the effect of aggregates- gradation variations on strength parameters and rutting property of hot mix asphalt (HMA).
b. Find best gradation for asphalt wearing course (AWC).

II. LITERATURE REVIEW

A soil is considered to be strong with respect to its engineering properties of shear strength, permeability and compressibility if it is well graded. Since strength is required for a good riding surface of the pavement, therefore, it should be the prime concern of a pavement engineer to guarantee a well graded asphaltic concrete mix for asphaltic concrete course (ACC). Because first ACC takes wheel loads which creates a huge amount of contact pressure of magnitude 2.5 tsf for tyre pressure of 85 psi of a wheel load of 9000lbs. This pressure can increase with tyre pressure and with wheel load, Sowers and Vesic [3]. If ACC is stronger, then according to Boussinesq's theory of stress distribution, the lower layers will be safe and will not contribute to the damage of the pavement.

HMA aggregate gradation is based on AASHTO T27 / ASTM D448-03 specifications, Irum [4]. Moreover, in Pakistan, NHA has its own limits based on AASHTO / ASTM specifications for asphaltic concrete paving mixture for wearing course. They are known as Class -A and Class -B gradations (Shamim [5]).

In the past sub grade deformation was considered to be the primary cause of rutting and many pavements design method applied limiting criteria on vertical strain at the sub grade level however the recent research have shown that most of the rutting occur in the upper part of asphalt surfacing layer which mainly depends on the aggregate gradation and natural properties of aggregates and on the properties of bitumen both of which are the governing constituents' of mix design and asphalt surfacing layer ,Ahmed et al., [6].

Singh *et al.,[7]* on their study of the role and effect of aggregate gradation on the mechanical response of asphalt mix, say that given a size range of aggregates, numerous aggregate gradations (and thereby numerous asphalt mixes) are possible. Based on these numerous combinations, it is essentially a cumbersome and time consuming task to study the laboratory or field performances for all such possible asphalt mixes. Moreover, type of asphalt binder, shape of aggregates, size of aggregates, ratio of aggregates gradation, They find that a typical asphalt mix, aggregates occupy about 85% and binder about 10% by volume in the mix the rests are voids .Their results shows that the mixes with coarse aggregates in high percentage are more stable and stronger.

Based on the above guidelines, five different gradations of asphaltic concrete are considered and tested in this paper for the purpose of finding an optimum mix to cope with the problem of rutting in ACC.

III. METHODOLOGY

A Laboratory Characterization of Materials (Based on AASHTO specifications).

a) Coarse Aggregates

The suitability of aggregates from Chsma baba quarry Karak for use in asphalt construction was determined by evaluating the material in terms of the followings**.**

- Size and grading
- Particle shape
- Absorption
- Toughness
- Soundness
- impact value
- Abrasion value.

b) Fine aggregates

Sand is the fine aggregate in HMA Relative Density and Absorption tests are done on this fraction of the HMA.

c) Characteristics of Asphalt Cement: For engineering and construction purposes, three properties or characteristics of asphalt are important i.e. consistency, purity and safety Gudimettla [8].

d) Marshall test of HMA: To find the behaviour of HMA in Marshall and wheel tracking tests, the considered gradations of the samples are shown in table 3.1.

Sample No.	Gradation
1	50% coarse aggregate +40% sand +10% (bitumen +filler + air)

2	60% coarse aggregate +30% sand +10% (bitumen + filler + air)
3	55% coarse aggregate + 35% sand +10%(bitumen + filler +air)
4	45% coarse aggregate +45% sand + 10% (bitumen +filler +air)
5	40%coarse aggregate + 50% sand +10% (bitumen + filler + air)

Table 3.1: Considered gradations and their sample Nos.

The suitability and strength of HMA mixture is measured from a compacted sample prepared from this HMA mixture. The apparatus used for the strength of this sample and HMA is Marshal Stability Meter / machine. The sample is loaded diametrically at the rate of 5cm per minute. The deformation and load are measured in mm and kg respectively. Volumetric relations are also found to establish a sound relation between voids, voids filled bitumen and amount of air which also affects the strength of HMA .So for an HMA design , the followings objectives found this Test:.

- Voids – density relationship
- Marshall Stability and Marshall flow.

The maximum load (kg / kN) carried by the sample at a temperature of 60°C in the machine is called Marshall stability number or value of the HMA mix. The flow value (mm) associated with maximum load is called flow value. It is measured in 0.25 mm units. All related tests are carried out to meet the criteria of NHA specifications (1998) for the asphalt concrete wearing course mixture. Indirect tensile strength tests in conditioned and in unconditioned states are done to know the freeze and thaw response of the mix.

e) Volumetric relationships: HMA mixture is made of three materials; aggregate, asphalt binders and air. Generally. HMA is described by its constituents' volume. It is important to know how these three materials relates to one another. Knowledge of these is used to find the amount of optimum binder content which controls the stability of HMA. Theses volumetric includes bulk specific gravity of the compacted asphalts mixture (G_{mb}), voids filled with asphalt (VFA), voids in mineral aggregates (VMA), air voids (AV) and theoretical maximum specific gravity of bituminous paving mixture (G_{mm}). 25 samples of considered gradation, five with the same binder content, are tested for optimum binder content to give maximum Marshall Stability and minimum flow. The samples are that mix are used for rutting determination.

f) Indirect tensile strength: The indirect tensile strength (IDT) of all the gradation is found out both in unconditional and conditional (frozen) state.

The IDT plays a vital role in effecting the rutting character of HMA. The values of IDT strength may be used to evaluate the relative quality of asphalt mixture in conjunction with laboratory mix design testing and for estimating the potential for rutting or permanent deformation. The results can also be used to determine the potential for the field pavement moisture damage when results are obtained on both moisture conditioned and unconditioned specim.

g) Sample testing for Permanent Deformation (Rutting) Wheel tracker test: In this test simulation of the deformation / rutting in the road surface course due to repetitive wheel loads is carried out. The sample in the shape of a slab is prepared in the given formwork and placed on platform of the machine. All data are input for number of passes per minute (frequency), depth recording etc. The computer software records and plots the graph between depth and number of passes in the sample is carried out. This apparatus is available in Sarhad University Peshawar.

Working of Wheel Tracker is as follows: The wheel tracker tray with the sample mounted in it is fixed under the wheel. The machine and the software attached are turned on. Then in the software the speed of the wheel was adjusted to 50ppm (passes per minute). Delay time was fixed as 1 minute. The number of passes was fixed to 12000.The wheel moves to and fro on the mounted sample with contact load of 5tonnes simulating road wheel load. LVDT and Load transducers measure these parameters of passes and load.

IV. RESULTS AND DISCUSSION

A. Raw Materials for HMA

Raw materials of crushed stone, sand and stone dust as a filler are collected from the local query. The particle size distributions of them is shown in figure 4.1. The five gradations of the HMA samples are prepared from them with addition of bitumen. These gradations are used for optimum bitumen content for the rest of laboratory tests on HMA for its suitability with respect to Marshall Stability and rutting resistance.

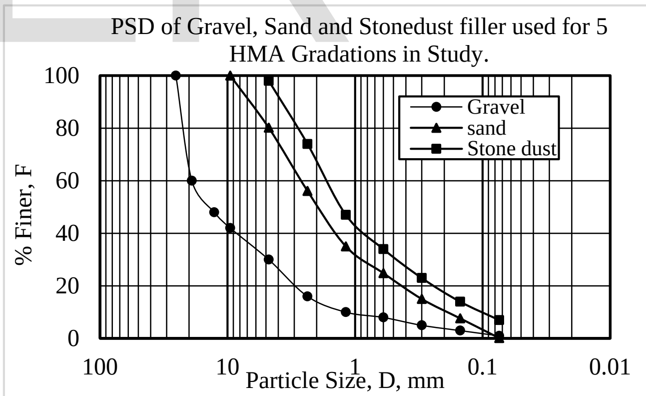

Figure 4.1: Gradations of HMA coarse, fine aggregates and filler , dust stone.

The gradation properties of these constituents are given in table 4.1. Coarse and fine aggregates and filler materials are of well graded nature according to unified soil classification system, USCS. This gives a dense mass of mixture.

Coarse Aggregates		Sand		Stone dust, filler	
Cu	Cc	Cu	Cc	Cu	Cc
16.67	1.13	15.88	1.76	17	1.47
Well graded gravel (GW)		Well graded sand (SW), with no fines		Well graded sand (SW), with 7% fines	

Sample No	Binder %	G_{mb} g/cc	VA %	VMA %	VFA %
1	3	2.28	8.2	15.89	40.82
2	3.5	2.43	6.78	15.2	52.91
3	4	2.47	5.4	14.6	63.2
4	4.5	2.47	4.82	15.02	71.23
5	5	2.46	4.2	15.2	75.54
Standard limits			4-8	14 min	65-75

Table4.1: Gradation of coarse, fine aggregates and filler used in HMA

Coarse aggregates		Binder	
Properties	Values	Property	value
Abrasion	23	penetration	68.3mm
Flakiness index,	4.75%	ductility	102cm
Elongation	4.4 %	Softening point	48°C
Bulk sp;gr.	2.67		
Water absorption	0.85 %	Sp gr	1.02
Impact value	12.06 %	-	-

samples.

All related tests are done on coarse aggregates to find its suitability as a flexible pavement materials. The data of these are shown in table 4.2. All of them meet the standards of NHA. Moreover, the related tests on bitumen are also done in the laboratory and the data are tabulated in table 4.2 It is found as per standards.

Table 4.2: Coarse aggregates and bitumen properties.

B. Considered Samples and NHA Gradation

The gradation of five samples considered in this study and that of NHA upper and lower limits are shown in table 4.3**.** It is based on the unified soil classification system (USCS). The five considered samples are blended as per this gradation for the preparation of HMA samples in which are bitumen / binder is added.

Sample No	Cu	Cc	Gradation
1	31.67	2.19	GW
2	6.33	1.62	GW
3	15	1.64	GW
4	24.50	1.59	GW
5	21.67	3.21	GP-SP
NHA Upper limit	28	3.58	GP
NHA Lower limit	30	3.33	GP

Table 4.3: Considered samples and NHA gradations.

C. Volumetric

To find the optimum binder content, tests are conducted on 5 HMA samples with a varying binder content but within the limits. These samples are prepared from the five considered gradations for HMA in this study. The data of all graphs are shown in table 4.4.

Table 4.4: Determination of optimum binder content.

It is seen from this table that for a maximum Marshall stability of 1538kg and minimum flow of 8.2mm, the optimum binder content comes out to be about 4%, which is within the recommended range of NHA. But for the sake of bitumen loss, it is taken as 4.2% which in used in the rest of the samples.

Sample No.3 is selected based on highest Marshall Stability and minimum flow given in the table, and is the best among five gradations with respect to strength and deformation. It shows that in the field with a gradation, it will show promising results with respect rutting too.

D. HMA Marshall Stability Tests

All the related laboratory tests are carried out on 25 samples of HMA in group of considered gradations. One of the data is plotted in figure4.2 for Marshall Stability and flow. Sample No 3 shows maximum stability value of 1420 kg (13.95kN) > 1000 kg (9.810kN) (standard) and with a corresponding minimum flow value of 8.32 mm (8 – 14mm, standard).

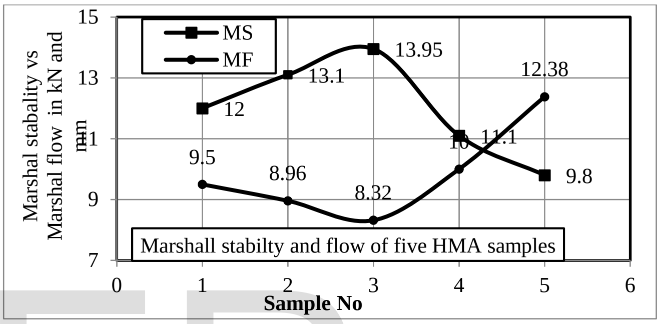

Figure 4.2: Marshall Stability and flow values of Five HMA gradations.

Table 4.5 shows all the Marshall and Indirect tensile strength related data of the five HMA samples prepared from five considered gradations. Gradation No.3 is the best among the five samples.

Property \ No		1	2	3	4	5
$Binder_{opt}$ (%)		4.2	4.2	4.2	4.2	4.2
Stiffness (kg /mm)		1.26	1.46	1.68	1.11	0.8
Marshall Stability (kg)		1223	1335	1421	1150	1000
Marshall flow (mm)		9.5	8.96	8.3	10	12.38
IDT (kN)	**unconditioned**	9.5	10.2	12.7	7.11	4.4
	conditioned	4.49	6.34	7.52	5.23	4
Load, P kN		154	160	199	118	112

Table 4.5: Marshall and Indirect tensile strength data.

E. Rutting Depth in HMA Samples

The results of the wheel tracker tests on the HMA samples fabricated from the considered gradation samples are shown below. The figures 4.3, 4.4, 4.5, 4.6 and, 4.7 show the graphs of these tests. All samples show a sudden yielding before 10,000 passes, 5 tonnes wheel load and 50 passes per minute, but sample No.3 shows minimum rut depth of 5.4mm when 12,000 passes complete, which means its more resistance as compared with that of sample No.5 with rut depth of 17mm.

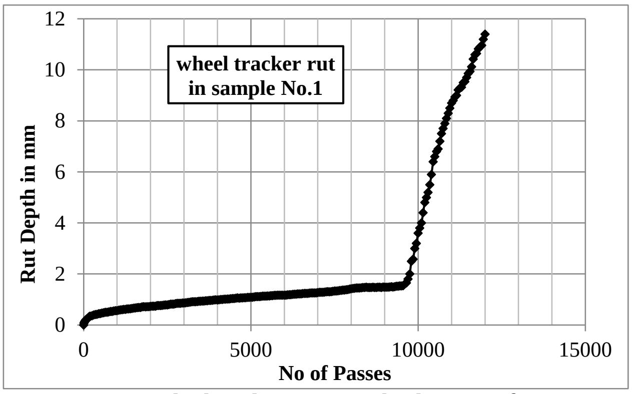

Figure 4.3: Wheel tracking test: rut depth VS No of passes.

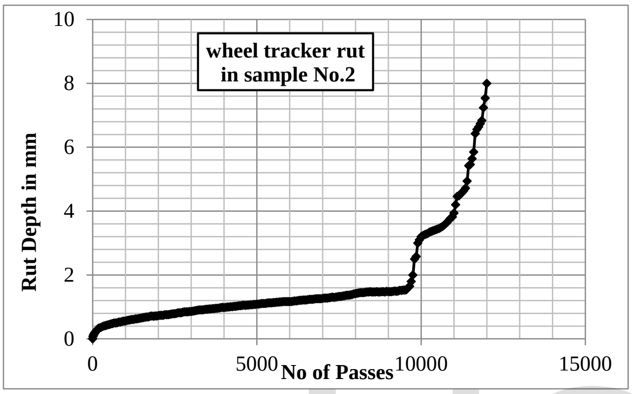

Figure 4.4: Wheel tracking test: rut depth VS No of passes.

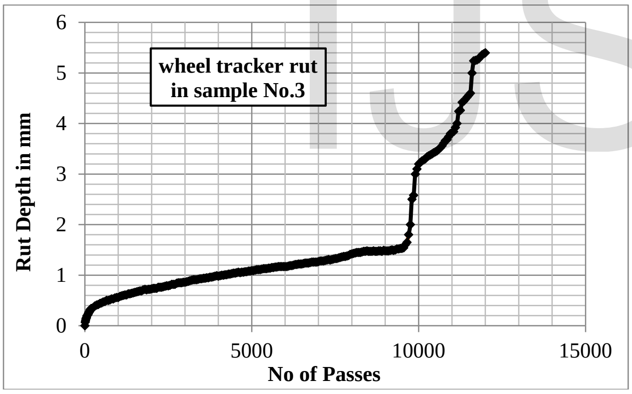

Figure 4.5: Wheel tracking test: rut depth VS No of passes.

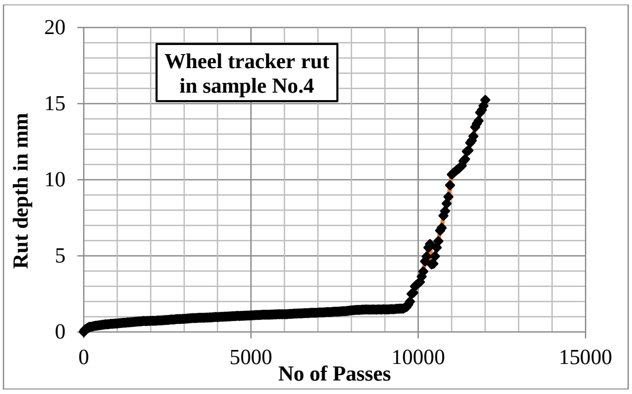

Figure 4.6: Wheel tracking test showing depth of rut in mm.

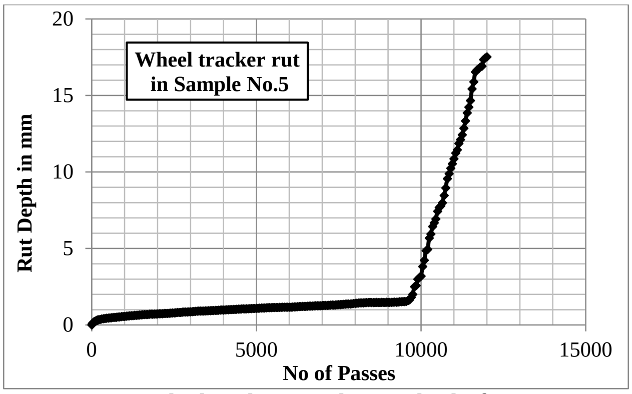

Figure 4.7: Wheel tracking test showing depth of rut in mm.

Figure 4.6, sample No.3, shows the minimum depth of rut of 5.4mm while figure 4.7, Sample No.5 shows maximum depth of rut equal to 18mm for the same loading and same number of passes. Table 4.6 carries depth of ruts for all the five HMA mixes.

Sample No	Rut Depth, mm
1	11
2	8
3	5.4
4	15.24
5	17

Table 4.6: Depth of ruts in HMA samples from wheel tracking tests.

V. CONCLUSION

From the results of the study, it is found that PSD plays an important role in the strength of HMA. This is demonstrated by the five considered gradations for HMA from both Marshall Stability tests and from Wheel tracker tests.

Sample No.3 is the strongest, out of five considered and tested samples. Its gradation is well graded gravel (GW) and has less amount of fines and more coarse size particles compared to others and compared to NHA gradations.

REFERENCES

1. George, K.P. and Uddin, W., 2000. Subgrade characterization for highway pavement design. *Final Report, Mississippi Department of Transportation, Jackson, MS.*

2. NHA, 2018. National Highways Authority, http://nha.gov.pk/en/.

3. GEORGE F. SOWERS and ALEKSANDAR B. VESIC, 1958. Vertical Stresses in Subgrades Beneath Statically Loaded Flexible Pavements, Georgia Institute of Technology.

4. Irum, S., 2013. Experimental investigation of various compaction temperatures on properties of hot mix asphalt (Doctoral dissertation, NUST).properties of hot mix asphalt (Doctoral dissertation, NUST).

5. **Shamim Zafar, 2012.** SELECTION OF AGGREGATE GRADATION FOR HOT MIX ASPHALT, Centenary Celebration (1912 – 2012) 381, Principal Material Specialist, NESPAK, LAHORE – PAKISTAN.

6. Ahmed, M.A. and Attia, M.I., 2013. Impact of gradation and type on hot mix asphalt rutting in Egypt. International Journal of Engineering Research and Applications (IJERA), 3(4), pp.2249-2258.

7.] Singh, A., Das, A. and Basu, S., 2012. A numerical study the effect of aggregate gradation on mechanical response asphalt mix. KSCE Journal of Civil Engineering, 16(4), pp.594-600.

8. Gudimettla, J.M., Cooley, L.A. and Brown, E.R., 2003. *Workability of hot mix asphalt*. NCAT.