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RUTTING AND MOISTURE SUSCEPTIBILITY ASSESSMENT OF ASPHALT WEARING COURSE GRADATIONS

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ABSTRACT

This research focused the impact of various aggregate gradations on permanent deformation and moisture susceptibility of asphalt concrete mixtures. Five wearing course of different gradation, namely NHA-A, NHA-B, SP-1, SP-2 and MS-2, were adopted. Two paving grade bitumen i.e. 40/50 and 60/70 were used. Hamburg Wheel Tracking Test (HWTT) and Modified Lottman test were performed to assess rutting propensity and moisture damage of asphalt mixtures. The results indicated the superior performance of NRL 40/50 binder in HWTT while mixes prepared with Parco 60/70 showed better resistance against moisture. In HWTT, NHA-A performed well followed by NHA-B and SP-2 while MS-2 and SP-1 failed the minimum rut depth criteria. All the mixtures passed the minimum benchmark for Tensile Strength Ratio (TSR). Aggregate gradation SP-1 given in Superpave guidelines provided greater resistance to moisture damage due to compact nature of the blend. Rutting tendency of the mixtures increased with increasing TSR and decreasing Indirect Tensile Strength (ITS).

KEYWORDS

Asphalt mixtures, Aggregate gradation, Rutting, Moisture damage, Tensile strength ratio

INTRODUCTION

Asphalt mixtures are used as a major paving material for the construction of roads all over the globe. In a world where road construction and its sustainability is of key concern the durability of asphalt is of major significance. Because of the increasing cost of bitumen, durable asphalt mixtures are attracting considerable attention. Pavement is subjected to continuous traffic loading and environmental effects throughout its entire life that causes distresses. During the last decade, researchers have tried to devise strategies to construct pavements with extended life span.

Hot Mix Asphalt (HMA) is composed of aggregate, bituminous binder and air voids. These should be combined in such a manner that the resulting mixture is able to sustain the traffic and environmental loading throughout its service life. Pavement constructed with HMA is classified as Flexible Pavement. The selection of a suitable aggregate gradation for asphalt mix design has been a controversial issue for long time as it shakes the HMA performance. Various transportation agencies have developed their own asphalt mix gradation as per their need. Both Nominal Maximum Aggregate Size (NMAS) and type of aggregate gradation disturbs the performance of asphalt mixture to resist permanent deformation and moisture susceptibility. In order to prepare HMA with better performance it is essential to know the percentage of aggregate passing for each sieve in the mix. Usually such mixes provide better resistance to external loadings that are composed of continuous and balanced gradations. The type and quality of the aggregate used also affects the performance of HMA [1]. If these effects and their consequences on the mix are known, then proper changes can be made in the construction of HMA to increase its performance [2].

In HMA pavements rutting is identified as major cause of distress by Strategic Highway Research Program (SHRP). It is a significant distress mechanism in asphalt pavements in the form of permanent deformation. Rutting in asphalt mixture consists of shear deformation and densification. Increase in volume or expansion occurs in asphalt concrete under load. The type of deformation that occurs due to expansion is also known as plastic or shear flow. Such deformation causes the disbonding at the interface of aggregate and binder or segregation and pavement deterioration. Therefore, when asphalt mixes are assessed for permanent deformation, it is essential to give more attention to their dilatant and shearing behavior in which viscosity increases with the rate of shear strain. Permanent deformation in flexible HMA pavements is a key source of serviceability loss and can cause major safety concerns. The vulnerability of asphaltic pavement to rutting primarily depends on the characteristics of bitumen and aggregate in the HMA mix. The prime mechanism of rut formation is known as densification. The decrease in volume occurs beneath the tires and is almost equal to increase in volume of adjacent upheaval zone. Shear distortion is deliberated as the main mechanism of permanent deformation during larger part of the pavement lifetime [3].

Proper structural design of pavement layers, the material properties of individual layers and construction quality control are equally important for a good and satisfactory performance of flexible pavements to resist the permanent deformation [4]. The mixes prepared with stiff bitumen and coarser aggregate particles are usually less prone to permanent deformation as compared to mixes composed of higher content of fine aggregate and bitumen. HMA mix designed in such a way that it contains binder of sufficient stiffness will increase ability of the pavement to resist rutting propensity [5]. The rutting resistance is mainly effected by gradation of asphalt mix. Open graded mixes exhibit the highest rutting while mixes with the coarser gradation have the lowest permanent deformation. Rutting had main linear correlation with Marshall flow with R_2 of 0.74 while Marshall Stability with R_2 of 0.21 had the lowest linear correlation with permanent deformation [6]. The mixes produced with finer gradation have lower value of creep ratio in comparison with coarser gradation. Also the coarser aggregate provides more resistance to rutting as compared to finer gradation [7].

Moisture susceptibility has been acknowledged as an important cause of distresses like stripping, raveling, cracking, rutting and loss of strength [8], [9], [10]. The premature failure of pavements is often caused by the presence of water in the form of isolated distresses due to asphalt binder film's debonding from the surface of aggregate or due to early rutting/fatigue cracking because of reduced strength of the mixture [11]. The major concern related to moisture is the potential for loss of adhesion bond and integrity between aggregate and binder generally called stripping. Grave situations arise because of the company of water saturation in the asphalt mixtures and high stresses of the traffic on the pavement. The most direct and damaging result of moisture effect is the reduction in the pavement strength [12]. It is one of the hidden effect as bottom portion of the asphaltic layer holds water for longer time because the evaporation rate is slow from the surface layers [13]. The lower portion of asphalt layer is in tension under the load of traffic [14]. In the presence of moisture and applied traffic loading the cohesion and adhesion bond within the binder-aggregate matrix starts degrading and it leads to earlier bottom up fatigue cracking [15]. The bitumen content in the mix considerably shakes the resistance of HMA mixes to water damage [16].

Although an extensive range of laboratory tests are developed to assess the moisture susceptibility but RP Lottman performed a research under NCHRP Project 4-08(03) and developed a test method commonly known as the Lottman test which was later modified and is a standard test under AASHTO designation T-283. It has been included in the SHRP guidelines for mix design as a basic test for moisture damage. The mix having the range of smallest content of air void and whose radius of the voids was small, was highly susceptible to be damaged by moisture as compared to asphalt mixture having more voids radius [17].

EXPERIMENTAL PROGRAM

Material selection and testing

Limestone aggregate was obtained from Margalla quarry. Two paving grade binders i.e. 40/50 and 60/70 procured from two refineries namely National Oil Refinery and Pak Arab Refinery Company, were used in the research. The characteristics of aggregate (e.g. texture, shape, degradation, strength etc.) and bitumen (e.g. grade, viscosity, ductility, specific gravity etc.) largely effect the properties of asphalt paving mixtures. Therefore, these tests were performed following ASTM, AASHTO and BS standards for characterization. The results are given in Table 1 and 2.

Tab. 1 - Tests on used Aggregate

Type of Test		**Result**	**Specification**	**Standards**
Los Angeles Abrasion		23.77%	45% (Max)	ASTM C 131
Flakiness Index		13.24%	15% (Max)	ASTM D 4791
Elongation Index		3.76%	15% (Max.)	ASTM D 4791
Aggregate Impact Value		16.33%	30% (Max.)	BS 812
Water Absorption	Fine Aggregate	2.33%	3% (Max.)	ASTM C 128
	Coarse Aggregate	0.81%	3% (Max.)	ASTM C 127
Specific Gravity	Fine Aggregate	2.52	-	ASTM C 128
	Coarse Aggregate	2.656	-	ASTM C 127

Tab. 2 - Tests on used Bituminous Binders

Test	Results		Standards
	NRL 40/50	Parco 60/70	
Penetration Test	45	66	ASTM D 5
Flash Point	297$_{o}$C	300$_{o}$C	ASTM D 92
Fire Point	331$_{o}$C	347$_{o}$C	-do-
Softening Point	55.8$_{o}$C	50.1$_{o}$C	ASTM C 36
Ductility at 25°C	>100cm	>100cm	ASTM D 113
Dynamic Viscosity	0.2826 Pa.sec	0.2701 Pa.sec	AASHTO T 316
Specific Gravity	1.04	1.03	-

Gradations and optimum binder content

Five midpoint aggregate gradations of wearing course were selected, which are given in Figure 1 and Table 3 and are defined as follow:

NHA-A: It is one of the coarser gradation selected from National Highways Authority (NHA) specifications of 1998. Its Nominal Maximum Aggregate Size (NMAS) is 19mm with 57.5% material retained on sieve No.4.

NHA-B: It is commonly used in Pakistan, and is defined in NHA specifications. Its NMAS is 19mm with 50% material retained on sieve No. 4 and 50% passed through it.

SP-1: It is the finest gradation among the five and is adopted from Superpave. It has an NMAS of 12.5mm but is composed of 65% fine materials.

SP-2: It is a coarser gradation given in Superpave. Although 55% of aggregates retains on sieve No. 4, it has NMAS of 12.5mm.

MS-2: It is a finer gradation given in Asphalt Institute's Manual Series-2 with NMAS 12.5mm and 59% of material passing from sieve No.4.

Tab. 3- Aggregate gradations for asphalt wearing course

Sieve Size		Asphalt Wearing Course Gradations Cumulative Percentage Passing				
		NHA-A	NHA-B	SP-1	SP-2	MS-2
		Pass %	Pass %	Pass %	Pass %	Pass %
1"	25.4 mm	100	100	100	100	100
3/4"	19 mm	95	100	100	100	100
1/2"	12.5 mm	76	82	94	95	95
3/8"	9.0 mm	63	70	87	84	82
1/4"	6.4 mm	51.5	59	74	57	69
# 4	4.75 mm	42.5	50	65	45	59
# 8	2.36 mm	29	30	37	30	43
# 16	1.18 mm	20	20	21	20	30
# 30	0.6 mm	13	15	14	15	20
# 50	0.3 mm	8.5	10	9	10	13
# 100	0.15 mm	6	7	7	6	8.5
# 200	0.075mm	5	5	5	4	6
Filler	Pan	0	0	0	0	0

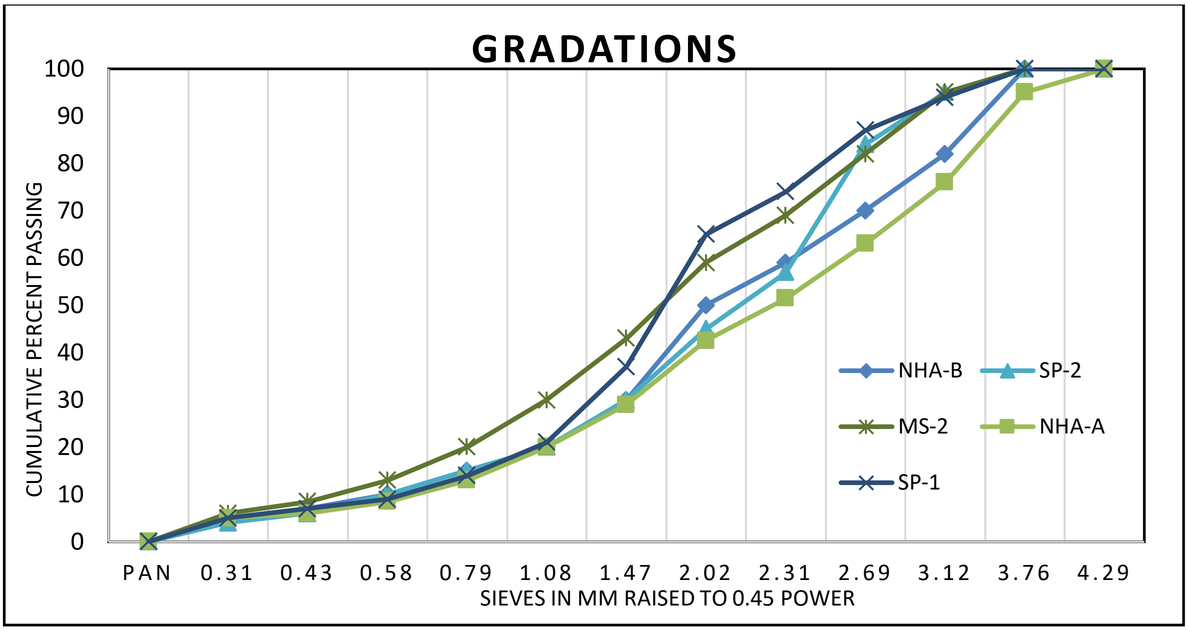

Fig. 1 – Aggregate gradations for asphalt wearing course

Marshall Mix design method (ASTM D6926) mentioned in Asphalt Institute Manual Series-2 was used to calculate the Optimum Bitumen Content (OBC) for all the mix combinations. Samples in triplicate having diameter of 4 inch and height of 2.5 inch were fabricated at 0.5% increment of bitumen content and were tested for stability, flow, maximum theoretical specific gravity (Gmm) and bulk specific gravity (Gmb) to find air voids, unit weight and voids in mineral aggregate. The bitumen content to produce air voids of 4% in the mixture was selected as OBC because all the other parameters of the mix design were well in the acceptable range. OBCs for all the asphalt mixtures are given in Table 4.

Tab. 4 - Optimum Bitumen Content (OBC) for Asphalt Mixtures

Aggregate Gradation	Binder	ID for Mixture	OBC %
NHA-A	NRL 40/50	NAN	4.1
NHA-B	NRL 40/50	NBN	4.3
SP-1	NRL 40/50	S1N	5.3
SP-2	NRL 40/50	S2N	4.5
MS-2	NRL 40/50	MN	4.8
NHA-A	Parco 60/70	NAP	4.0
NHA-B	Parco 60/70	NBP	4.2
SP-1	Parco 60/70	S1P	5.1
SP-2	Parco 60/70	S2P	4.4
MS-2	Parco 60/70	MP	4.9

Performance tests

Rutting propensity (Hamburg wheel tracking test)

A total of 30 gyratory specimens of 6000g each were prepared by using OBC, for the 10 blends, in laboratory by following Superpave mix design method. For each sample aggregates were first dried thoroughly in the oven at 105 ±10°C and mixed mechanically along with the binder at 160$_o$C. The mix was then aged for 2hrs at 135$_o$C and then compacted by giving 125 gyrations. The specimens were first cut with saw cutter in standard dimensions of 152.4mm diameter and 38.1mm height and then tested for rutting propensity in wet condition. In this research, wet mode at 50$_o$C was selected to determine permanent deformation of each blend. The failure criterion was selected as 12.5mm depth of rutting at 10,000 passes. Figure 2 shows the sample after testing for rutting.

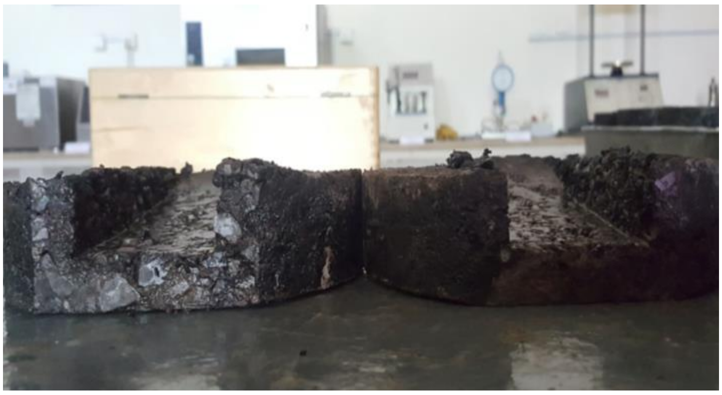

Fig. 2 – Hamburg Wheel Tracker Sample after Testing

Moisture susceptibility (Modified Lottman test AASHTO T-283)

The test was performed by following AASHTO T-283 standard. Six Marshall test specimens (4inch diameter and 2.5inch height) were prepared for each blend using OBC with ageing time of 16hrs before compaction and were separated into two groups of three samples each. One subset was tested unconditioned, by placing in water bath at 25 ± 1$_o$C for 1 hr., for Indirect Tensile Strength (ITS) in Universal Testing Machine (UTM). The conditioned set is saturated (according to T-283 procedure) by placing it in a vacuum container (10 – 26 in. Hg) such that 1 inch of water is above its surface. Saturation level of 70 – 80 % was attained for all the specimens. This subset was then wrapped in a thin plastic film and sealed in a plastic bags with little water and subjected to freeze cycle (16hrs ± 1 hrs.) followed by thaw cycle in a water bath at 60 ± 1$_o$C for 24 hrs. Subsequently it was placed in water bath of 25 ± 1$_o$C for 1 hour to attain room temperature and then tested for ITS. A minimum of 85% TSR was selected as a failure criterion for this test. TSR was found by using equation 1:

$$TSR = \frac{S2}{S1} x\ 100 \qquad (1)$$

S1 = Tensile Strength (Avg.) of Dry set,

S2 = Tensile Strength (Avg.) of Conditioned set

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RESULTS

The results of both performance tests are summarized in Table 5 given below:

Tab. 5 - Performance tests results

Mix Description	Mix ID	S1 (Average)	S2 (Average)	TSR = S2/S1 *100	Rut Depth (Average)
		kPa	kPa		(mm)
NHA-A, NRL 40/50	NAN	895.89	779.68	87.03	3.692
NHA-A, Parco 60/70	NAP	880.53	782.12	88.82	4.011
NHA-B, NRL 40/50	NBN	877.72	790.83	90.10	4.913
NHA-B, Parco 60/70	NBP	859.11	792.22	92.21	5.559
SP-2, NRL 40/50	S2N	835.91	785.5	93.97	7.891
SP-2, Parco 60/70	S2P	819.34	784.7	95.77	9.917
MS-2, NRL 40/50	MN	813.98	788.69	96.89	13.723
MS-2, Parco 60/70	MP	801.77	777.3	96.95	14.272
SP-1, NRL 40/50	S1N	783.11	760.03	97.05	15.718
SP-1, Parco 60/70	S1P	764.2	742.63	97.18	16.154
S1 = Average ITS of un-conditioned specimens, S2 = Average ITS of conditioned specimens					

Rutting propensity

The results of HWTT are given in Table 5. Figures 4 illustrates that blends prepared with NRL 40/50 binder performed better than that of Parco 60/70 because of more viscosity of the former and its enhanced resistance to high temperature. This can be confirmed by its higher softening point as well. NHA-A being a comparatively coarser gradation, due to larger aggregate particles, has the least rutting potential followed by NHA-B and SP-2 while SP-1 and MS-2 gradations failed this test. This is due to the fact that coarser particles provide better strength to the mixture. Although MS-2 and SP-1 performed well in the other test but being relatively finer gradations, having higher percent of passing on sieve No. 4, failed by attaining more than 12.5mm rut depth in wheel tracking device prior to the completion of 10,000 passes. It can be explained by the inability of fine particles to sustain more load of the wheel. Rut depth of mixtures increased with increasing TSR and decreasing ITS.

Moisture susceptibility

Moisture damage was calculated by finding TSR of each asphalt mixture as it is an important criterion for moisture susceptibility. It is the tensile strength’s ratio of unconditioned test specimens to that of conditioned set. The results of TSR are demonstrated in Figure 5, Figure 6 and in Table 5. The results of TSR showed that finer gradation of SP-1 provided better resistance to moisture damage followed by mixtures of MS-2, SP-2, NHA-B and finally NHA-A gradation. NHA-A being a coarser gradation has the least TSR. As moisture damage highly depends on gradation therefore coarser gradation is less resistant to moisture damage as compared to highly dense finer gradation. This can also be explained as coarse gradation contains less material passing from sieve # 200 (75μm) which in turn reduces the TSR. These fine particles fill the voids, increasing density of the mix making it resistant to water damage. Also, during the compaction larger aggregate particles present in the mix are broken producing uncoated aggregate surfaces, as shown in Figure 3, which absorb water easily and cause stripping in mix. ITS values compared in Figure 5 also confirm the high strength of coarser gradations when tested unconditioned.

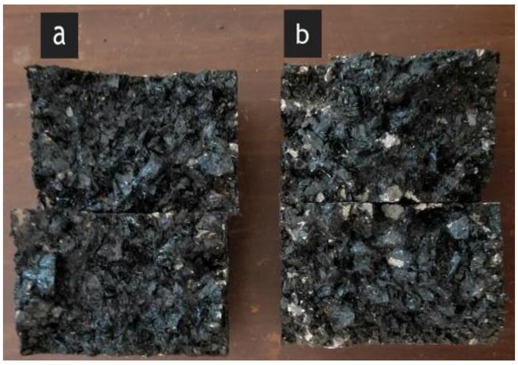

Fig. 3 – TSR Samples: (a) Unconditioned (b) After Conditioning

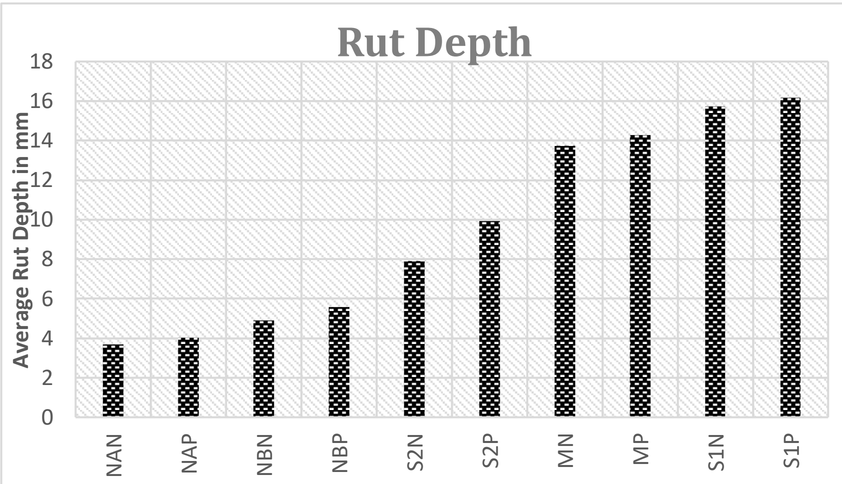

Fig. 4 – Average Rut Depth from Hamburg Wheel Tracker Test

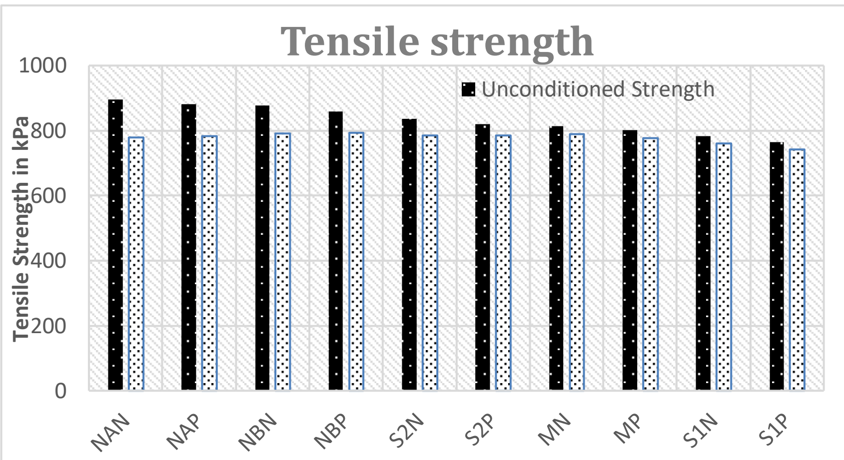

Fig. 5 – Average tensile strength values of different mixtures

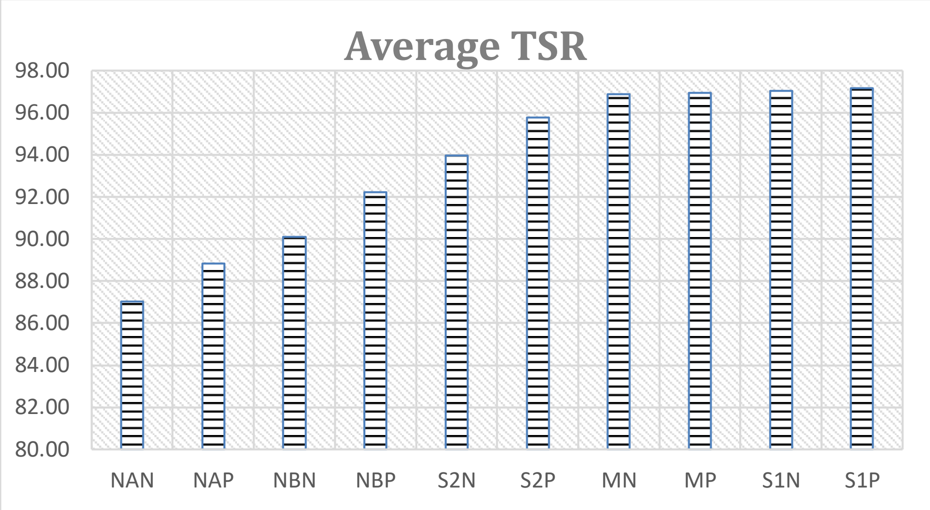

Fig. 6 – TSR values of different asphalt mixtures

CONCLUSION

Ten (10) bituminous mixtures were produced using five (05) kinds of wearing course gradations with two (02) binders of different source and were tested for rutting and moisture sensitivity. Following conclusion can be drawn from this study:

- The HMA blends prepared using NRL 40/50 binder performed better than that of Parco 60/70 in wheel tracking test and vice versa in modified Lottman test because of the extreme conditioning regime in the later, which involved freezing and thawing of specimens.
- NHA-A showed better results in HWTT due to its coarser stone structure followed by NHA-B and SP-2 gradation while the finer MS-2 and SP-1 gradation failed the test because of their inability to sustain heavy traffic loads.
- All the mixes passed the TSR test as the minimum specified limit is 85%. SP-1 i.e. finer gradation provided more resistance to water damage due to its highly dense structure followed by the MS-2, SP-2, NHA-B and lastly NHA-A gradation.
- The mix with high unconditioned ITS provides more resistance to permanent deformation or rutting. Also, rutting potential increases with increased TSR due to finer gradation of the mix.
- It can be concluded that a balance of fine and coarse aggregate should be maintained in order to achieve rut and moisture resistance mix.
- NMAS and total passing from sieve No 4 are key gradation factors for performance of asphalt mix. Greater NMAS in the mix will provide a better resistance to rutting while higher amount of fine aggregate passing sieve No. 4 will ensure less moisture damage. Therefore, NHA-A and NHA-B gradations are recommended to be used because of higher rut resistance and satisfactory results of moisture damage. In areas with heavy rainfall, SP-2 gradation may be adopted keeping in view the loading regime of the highway.

CONFLICT OF INTEREST STATEMENT

The authors certify that this research was conducted as a part of Strategic Pavement Research program initiated by National Highways Authority NHA, Pakistan in order to characterize and standardize materials and methods for maintenance and rehabilitation of national highways and motorways across Pakistan.

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