4th Conference on Sustainability in Civil Engineering (CSCE'22)
Department of Civil Engineering
Capital University of Science and Technology, Islamabad Pakistan

RUTTING-DENSIFICATION MITIGATION MEASURES FOR PAVEMENTS OF PAKISTAN-SUSTAINABLE WAY FORWARD

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Abstract- The concept of having layers in flexible pavement is to sustain and distribute the heavy traffic load of the vehicles to the subsequent layers. Due to insufficient compaction of the asphalt concrete, the surface layers (wearing and base) continue to densify under loads resulting in the rutting densification. Rutting in the pavement considerably reduces the service life. For this purpose, different factors resulted into insufficient compaction of pavements in Pakistan need to be identified. Mitigation measures for rutting densification are required to be proposed for improvement of pavement life-cycle. Roads exhibiting rutting-densification were identified. Core samples of asphalt concrete surface layers (wearing and base) were collected from the roads. Density of these core samples were determined and compared with volumetric of mix design adopted during construction. The laboratory samples were prepared in accordance with volumetric of the extracted road core samples. These samples were tested in wheel tracking machine for determination of the rut-depth. Rutting depth determined in laboratory is compared with actual field data of rutting. Results indicate that NHA class B is 43% more susceptible to rutting than NHA class A. Effects of different factors like mix volumetric, aggregates shape, and asphalt content etc. on laboratory and field rutting were evaluated. Necessary mitigation measures to control rutting densification phenomenon for future sustainable pavements in Pakistan are also proposed.

Keywords- mitigation, pavements, rutting densification, sustainable

1 Introduction

The design of pavements should be such that it must withstand the stresses against axle loads, moisture change and environmental temperatures. The design of pavements should also meet the major distresses like rutting, fatigue, cracking etc. acceptance criteria. Pavements should have sufficient skid resistance for the smooth movement of the vehicles. The elastic modulus is the parameter which reflects the densification of asphalt mix. Densification of asphalt mix is a function of aggregates, asphalt mixing methodology, asphalt mix volumetric, field preparation and compaction, temperature and moisture damage etc. inappropriate/insufficient densification of asphalt mixes lead towards rutting in surface course as shown in Figure 1. Rutting is the most important type of distress occurred during the life cycle of the pavement. Therefore, it is desirable to minimize the rutting. Rutting normally occurs in three types as shown in Figure 1. Rutting densification majorly observed in the top of Asphalt concrete pavements. Asphalt concrete pavements have shown variations in the performance so there is a need to correlate the asphalt concrete properties to the pavement performance. (Rizvi, Khan et al. 2021).

Rutting is the load related distress. Although all the pavement layers (base, subbase, subgrade) contribute to rutting but the contribution of asphalt concrete layer towards rutting is very significant. The pavement network in Pakistan experiencing premature rutting in asphalt concrete layer. The structural design of pavements is based primarily of the empirical relationships developed through research and field experience. Today the design methodologies for the flexible pavement falls in two categories, empirical and mechanistic-empirical. Main aim of both these design considerations is to limit the horizontal tensile strain at the bottom of asphalt layer to limit fatigue cracking and to limit the vertical compressive strain at the top of subgrade to prevent rutting. Extensive rutting lead towards structural failure of pavement and cause serious issues like hydroplaning. Rutting in the asphalt concrete layer is generally due to the lateral distortion and shear deformation.

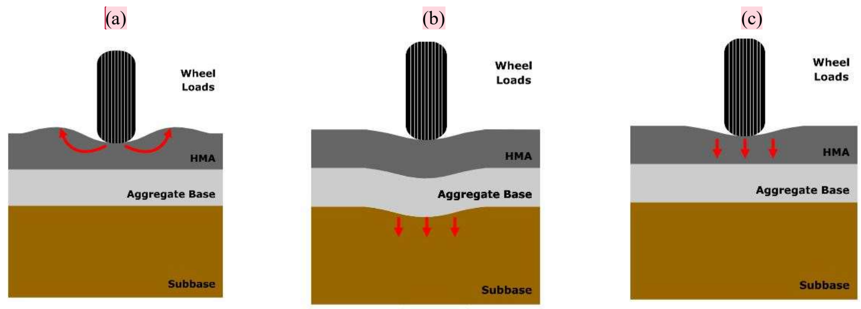

Fig 1: Rutting types a) mix rutting b) subgrade rutting c) densification Source: https://pavementinteractive.org/

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Asphalt rutting is the permanent deformation in the wheel path in the longitudinal direction on the surface of the pavement due to repeated application of heavy vehicles. The main causes of asphalt rutting is plastic deformations due to the exposure of moisture in the mix design, traffic consolidation and stripping of asphalt. Asphalt rutting negatively effects the life cycle of pavement. The main reason of asphalt rutting is change in temperature of environment, stiffness of mix design and increase in traffic loads. Rutting mostly occurs at high temperature and low frequency loading. Rut depth and width is also affected by thickness of HMA layer, material quantity, traffic loads and environmental condition. There are three stages for the development of rut in the asphalt layer. Initial, intermediate, and final stages according to load repetitions. In the initial stage, the densification occurs at a very fast rate primarily due to consolidation (volume change). In the intermediate stage, the constant rutting occurs throughout the life of the pavement. In the final stage, accelerated rutting occurs primarily due to shear deformation (plastic flow).

When densification occurs in HMA layer the aggregate rearrange themselves result in the decrease in air void content when densification increases with time and traffic the stability of the mix increased due to which the rate of rutting decreased. This is called strain hardening. Generally, the void content in newly constructed HMA pavement is 7% which reduces considerably (3-5%) in a period of two years. At that point the density of the mix is called ultimate density (at which the shear deformation is usually optimized for meeting the demands of traffic). The factor affecting the ultimate density are degree of initial compaction, material Properties, mix design, weather conditions, traffic, HMA thickness[16]

Pavement sustainability is defined as pavement having longer life, good reliability, minimum acceptable life cycle cost and environmental impacts. The failure of pavement earlier than design life is common problem. We lack in best practices and lesson learnt from the design and construction of the pavement. The current design methodologies of designing flexible pavement are not sufficient to explain sustainability in pavement construction. Sustainable policies are needed for evaluating the pavement in terms of environmental, performance, economic and optimized solution from given alternatives for design and construction. Using local available construction material, recycled use of aggregates and using green technology can contribute to sustainable pavements. The criteria of sustainable pavements are optimizing the use of natural resources, reduce the GHG emissions, reduce air, water and noise pollution and improving health, safety and comfort. Sustainability must be incorporated in every activity from the initial planning to the final phase of the construction. To prevent rutting the proper mix design methods, workmanship during construction, proper material specifications, proper compaction at the site are necessary.[18]

The most advance technique to reduce rutting is the use of geo-synthetic reinforcement and minimizing the exposure of moisture in the mixture during the construction quality control. The use of open graded, dense graded and stone filled aggregates in the mixture also reduce the rutting considerably [15]. Following are the objectives of the study

- To identify the roads in and around Lahore that exhibit rutting densification
- To evaluate the characteristics of identified roads materials
- To determine rutting of identified road mixes in field and laboratory
- To compare field and laboratory rutting
- To propose suitable measures to reduce rutting densification

2 Experimental Procedures

Table 1 presents the summary of tests carried out under the experimental programme.

Table 1 shows the experimental procedures employed for carrying out this study.

Sr. No	Test Name	ASTM Designation
1	Sieve Analysis of aggregates	ASTM D6913
2	Loss of abrasion, wear (%)	ASTM C131
3	Plasticity index value	ASTM D4318
4	Softening point	ASTM D36
5	Penetration at 25℃,100 g,5 sec	ASTM D5
6	Penetration of residue % of original	ASTM D5
7	Ductility at 25℃,5cm/min	ASTM D113
8	Ductility of residue at 25℃, 5cm/min	ASTM D113
9	Loss on heating, 163℃, 5 hours (%)	ASTM D6
10	Solubility (%)	ASTM D4
11	Specific Gravity at 25℃	ASTM D792
12	Stability(kg)	ASTM D6927
13	Flow-0.25(mm)	ASTM D6927
14	Voids in mineral aggregates (VMA %)	ASTM D6995
15	Voids in filled with asphalt (VFA %)	ASTM D6995
16	Unit weight (PCF)	ASTM D2726
17	Loss in stability (%)	ASTM D6927
18	Resilient Modulus	ASTM D7369

3 Research Methodology

Following methodology was adopted to achieve the objective of study

Extensive review of possible reasons of rutting densification across the globe

Various national and international conference proceedings, journals, books etc. were consulted related to review of literature and existing practices in control of rutting and its necessary remedies. The review of literature reveals that mix design and mix laying are two crucial factors in rutting densification [1-7]. Few noticeable works include [17] indicates that rutting can occur due to softening of base, sub-base and roadbed material. The major reason is the moisture infiltration. Rutting can be countered due to softening of binder at elevated temperatures as well as insufficient construction practices [18]. Rutting can also be encountered due to overloading of vehicles. Due to inadequate structural design of thickness the probability of rutting increases. Rutting generates in asphalt layers due to three mechanisms: loss of materials, densification and lateral plastic flow (or shear-related deformation), of which the shear-related deformation constitutes the majority of current studies associated with rutting.

Selection of pavement conditioning survey criteria for evaluation of rutting densification

Highway distress identification manual for the long term pavement performance programme criteria was used to describe the rutting. The method described in Figure 2 was used for the determination of the rutting. Straight-edge of 1.2m is placed transversely over the portion of the road where rutting was occurred. The maximum vertical distance from the bottom of the straight edge to the top surface of the pavement is measured with a gauge and is reported nearest millimetre as the rut depth. [19]

Rutting (Overall Condition) (Asphaltic Concrete Pavement)

Slight: Rutting 6.35mm to less than 12.7mm deep.

Moderate: Rutting 12.7mm to less than 25.4mm deep.

Severe: · Rutting 25mm deep or greater

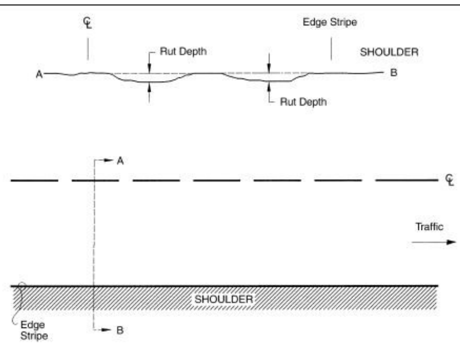

Figure 2: Pavement conditioning survey criteria

Identification of roads prone to rutting densification

The pavement section selection was accomplished by surveying the routes physically. The main criterion used in this selection is that the selected sections should represent the spectrum of pavement cross section, paving materials and traffic volume. Rut depth of these roads were measured. Inspect, measure and record the extent and severity of rutting. Roads exhibiting rutting were identified and labelled as test site in a survey and described in figure 3.

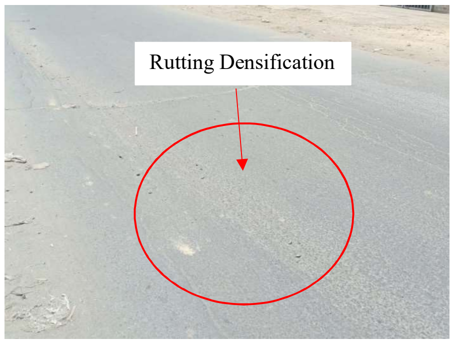

Figure 3: Identification of roads

Collection of core samples & test pits samples of surface course from rut prone roads

Core samples of two roads having NHA A class and NHA B class exhibiting rutting were collected and described in figure 4. Cores were obtained by using a power auger equipped with 6/4-inch coring bit. For thin AC layers 6 inch diameter coring bit was used and for thicker layer 4 inch coring bit was used. These produced enough material for testing according to ASTM. Most of the cores obtained from wheel paths were utilized for measurement of bulk specific gravity, layer thickness and extraction testing to determine material properties.

Figure 4: Collection of core samples of rut prone roads

Preparation of laboratory mix samples as per gradations found at roads for wheel tracker tests

Various laboratory tests were conducted to assess the physical and engineering properties of core materials obtained from the test site. The cores sample size 150mm diameter and 75 mm height may be obtained by compacting to a target height or by sawing one face (which will, subsequently, be the "bottom" face of the test specimen) to desired height. It is not permitted to saw both faces of the specimen to obtain the required specimen height for laboratory evaluation of two sample of NHA class A and NHA class B, samples are prepared in field and described in figure 5.

Figure 5: Preparation of laboratory mix sample

Performance of wheel tracker test for determination of laboratory rutting of the mixes observed at road

Laboratory evaluation for the rutting performance is done by performing the wheel tracking test (WTT). Different types of devices were developed to carry out this test under the principle of measuring the permanent deformations that occur in the mixture when it is subjected to a loaded wheel. The rut depth was measured on the sample at 1 min intervals with a linear variable differential transformer (LVDT) as shown in figure 6.

Figure 6: Wheel Tracker Test

Wheel tracker test:

The wheel tracking test (WTT) has been widely used as a standard laboratory test to evaluate the rutting resistance of asphalt mixtures. One sample of each NHA class A and NHA class B are prepared. Specimen diameter is 150mm and height is 62mm. Test samples can be in the form of beams or cylinders. Beams are typically compacted with the asphalt vibratory compactor while cylinder samples are typically compacted with the Super pave Gyratory Compactor (SGC).Cylindrical samples compacted to 4-percent air voids and beam samples compacted to 5-percent air voids resulted in wheel tracker laboratory test results that were more closely related to field rutting performance than did cylindrical and beam samples compacted to 7-percent air voids.The system must take rut depth measurements at least every 100 passes of the wheel. Test temperature significantly affects measured rut depths. As test temperature increases, APA rut depths increase. Samples tested at a test temperature corresponding to the high temperature PG specification better predicted field rutting performance than did samples tested at 6°C higher.Rut depth at every 5000, 10,000, 15,000, 20,000 passes and at the failure of sample is recorded.

Assessment of possible reasons causing the rutting densification on the roads by comparing the pavement design criteria with actual post construction parameters

1- Traffic consolidation
2- Stripping of asphalt
3- Improper compaction at site
4- Stiffness of mix design
5- High temperature

The performance criterion for total permanent deformation is defined in terms of maximum rut depth in the wheel path. Typical maximum rut depth for total permanent deformation are on the order of 7 to 12mm. Design should not exceed HMA rutting level of 10mm within design period.

4 Results

Results of extensive review of possible reasons of rutting densification across the globe

Rutting is one of the most common distress observed in asphalt mixes. Various factors can contribute towards the propagation of rutting in asphalt mixes. Various agencies described their own criteria's for the identification and evaluation of rutting in asphalt mixes. Asphalt mix inappropriate design and its inappropriate laying in the field using desired resources are the key components that result into rutting-densification of asphalt mixes.

Results of selection of pavement conditioning survey criteria for declaration of rutting densification

For declaration of rutting densification the procedure described in highway distress identification manual was used as shown in figure 7. Straight-edge of 1.2m is placed transversely over the portion of the road where rutting was occurred. The maximum vertical distance from the bottom of the straight edge to the top surface of the pavement is measured with a gauge and is reported nearest millimetre as the rut depth.

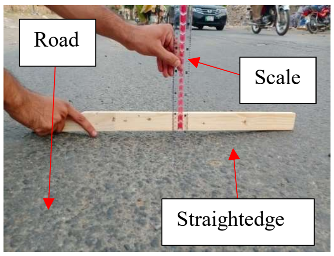

Figure 7: Rutting measurement in accordance with the distress identification manual

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Results of identification of roads prone to rutting densification

Rutting in asphalt layer is caused by combination of volume change and shear deformation due to the application of traffic load. It has been observed that shear portion is more significant than the volumetric one. The major portion of the rutting occurs during initial loading. Using the above described procedure and the material parameters in Tables, the rutting was measured 3mm as measured with 1.2m straightedge as shown in figure 8.

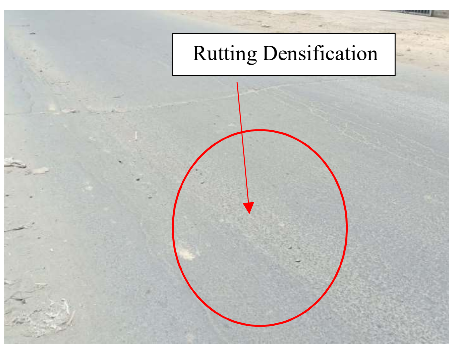

Figure 8: Rutting identification in the field

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Results of collection of core & test pits samples of surface course from rut prone roads

From NHA class A and B roads cores are collected and tests are conducted on it at binder, aggregate and mix level and results are shown in table 2, 3, 4 and 5.

Table 2: Asphalt test of sample NHA class A & B

Test Parameter	Temperature	Units	Results (NHA Class A)	Results (NHA Class B)	Method
Penetration	25℃	--------	63	66	ASTM D5
Penetration of Residue% of original		%	78	74	ASTM D5,D6
Ductility	25℃	cm	Above 100	Above 100	ASTM D113
Ductility of residue			Above 100	Above 100	ASTM D113,D6
Loss on heating	163℃	%	0.06	0.07	ASTM D6

Solubility	--------	%	99.8	99.70	ASTM D2042
Flash Point	--------	℃	305	298	ASTM D92
Softening Point	--------	℃	46.5	47	ASTM D36

Table 3: Optimum bitumen content of NHA class A & B

Mix Type	Asphalt Wearing Course
Proposed optimum A.C % by Weight of mix (Class A)	4.25 $\pm$ 0.3%
Proposed optimum A.C % by Weight of mix (Class B)	4.0 $\pm$ 0.3%

Table 4: Aggregate gradation of NHA class A & B

Sieve Size	% Passing (NHA Class A)		% Passing (NHA Class B)	
	Obtained	**Required Limits (Class-A)**	**Obtained**	**Required Limits (Class-B)**
1″	100	100	----	----
3/4″	95	95-100	100	100
1/2″	----	----	82	75-90
3/8″	42.50	56-70	70	60-80
No.4	29	35-50	50	40-60
No.8	8.50	23-35	30	20-40
No.16	10	5-12	10	----
No.50	----	----	----	5-15
No.200	5	2-8	5	3-6

Table 5: Asphalt mix properties of sample NHA Class A & B

Test Property	NHA Class A	NHA Class B	Required
	Obtained	**Obtained**	
Stability(kg)	1106	1063	1000 min
Flow-0.25(mm)	13	12.5	8-14
Voids in mineral aggregates (VMA %)	15.5	15.25	12-20%
Voids in filled with asphalt (VFA %)	73.25	72.5	65-75
Unit weight(PCF)	144.41	148.9	Not specified
Loss in stability (%)	13	15	20 max
Resilient Modulus (0.1 sec)	8000 MPa	7000 MPa	5000+

Resilient Modulus (0.3 sec)	6000 MPa	6400 MPa	5000+

Comparison of rut depth of NHA class A & B:

Field data of rutting of two roads having NHA class A and B is compared and results are shown in figure 9.

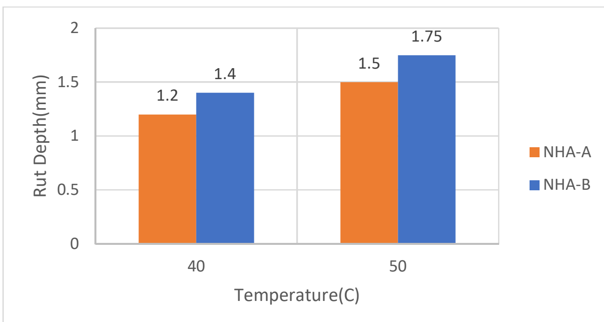

Figure 9: Rut Depth vs. NHA class A and B

5 Practical Implementation:

Every year both provincial and federal governments of Pakistan allocate having budgets for rehabilitation overlaying and improvement of roads. This research helps to provide guidelines and database for stockholders engaged in road maintenance and design for optimization of cost and performance.

6 Conclusions

Following conclusions may be drawn from the finding of this research.

- It was observed during survey that rutting densification was mostly occurred under the wheel path of vehicles. Rutting was observed more pronounced at a distance of 1m from centerline and edge on both sides of 6m wide under study city roads. The roads where asphalt wearing course was laid with asphalt mix designation NHA B exhibited 43% more rutting than roads laid with NHA A mixes under almost comparable traffic loading.
- Resilient modulus is the most important characteristics of asphalt mix material to control the rutting densification. NHA class A having resilient modulus 8000MPa at 0.1 sec is greater than the resilient modulus value of NHA class B having value 6000 MPa at 0.1 sec (25%greater). NHA class A having resilient modulus 7000MPa at 0.3 sec is greater than the resilient modulus value of NHA class B having value 6400 MPa at 0.3 sec (9%greater).
- The major reasons contributing towards rutting densification can be ranked as below
    - Overloading of vehicles
    - Maintenance issues
    - Non-adoption of performance mixes
    - Lateral movement of material
    - Softening of base, sub-base due to moisture infiltration

To prevent rutting the proper mix design methods, workmanship during construction, proper material specifications, proper compaction at the site are necessary. The most advance technique to reduce rutting is the use of geo-synthetic reinforcement and minimizing the exposure of moisture in the mixture during the construction quality control. The use of open graded, dense graded and stone filled aggregates in the mixture also reduce the rutting considerably.

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