# Repeated Load Permanent Deformation Behavior of Mixes With and Wihtout Modified Bituments

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## ABSTRACT

**Premature rutting in flexible pavement structure is being observed on most of the road network of Pakistan. It initiates primarily due to uncontrolled axle loading and high ambient temperatures. NHA (National Highway Authority), Pakistan has continuously been modifying aggregate gradations and penetration grade of bitumen, without any prior investigation of the mix behaviour under the prevailing axle load and environmental conditions of the country.**

**A comprehensive laboratory investigation was carried out on six mixes ranging from finer to coarser. Specimens were subjected to cyclic loading on UTM-5P (Universal Testing Machine) to study the resistance against permanent deformation of the mixes at 25, 40 and 55$^0$C. At low temperatures and stress levels, both coarse and fine graded mixes showed less accumulated strain, whereas at higher temperatures and stress levels, coarse graded mix with PMB (Polymer Modified Bitumen) showed good resistance to permanent deformation.**

**Key Word:** **Flexible Pavement, Repeated Loading, Permanent Deformation, Polymer Modified Bitumen.**

## 1. INTRODUCTION

Total transport in Pakistan has been reported to be around 239 billion passenger-km and 153 billion ton-km, from which around 90% plied on roads. The average payload of empty truck is around 7 tons and that of loaded is 10 tons, out of which 73% have been reported to be loaded and 27% are empty [1].

Increased loading pattern being one the major causes of premature failures, have been observed on almost all the heavily trafficked sections. Researches have been underway to address the critical issue. The goal of this research was to establish relationships between the permanent deformations in terms of plastic strain ($\varepsilon_p$) of asphalt concrete mixtures and stress levels at three temperatures.

## 2. LITERATURE REVIEW

One of the best approaches to determine the permanent deformation characteristics is to perform the RLPD (Repeated Load Permanent Deformation) test as a function of load repetitions [2]. Kamal, et. al. [3] studied the insitu

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behavior of bituminous mixes at RLPD with and without PMB under the same temperature and concluded that a drastic reduction of about 85% in resilient modulus was observed for an increase in temperature from 25-40$^0$C.

Kamal and Niazi [4] evaluated the effect of different stress levels and temperature on two aggregate gradations (coarse and fine) of asphaltic base course using PMB and reported that at low temperature (25$^0$C) and stress level (100 kpa), the coarser mix were less susceptibility to permanent deformation as compared to finer mix. At high temperature and stress level, shift in behavior of both the mixes was observed.

Fujie, et. al. [5] studied the relationship between the number of load repetitions and permanent deformation and found to include three distinct stages, namely the primary, secondary and tertiary stages.

Primary stage has high initial level of rutting, with a decreasing rate of plastic deformations, predominantly associated with volumetric change. Secondary stage has small rate of rutting exhibiting a constant rate of change of rutting that is also associated with volumetric changes; however, shear deformations increase at increasing rate. While the tertiary stage has a high level of rutting predominantly associated with plastic (shear) deformations under no volume change conditions [6].

According to Mwangi [7], the stiffness and resistance to permanent deformation of asphalt mixtures strongly depends on the mixture composition, degree of compaction, rate of loading and temperature.

Ziari and Mahid [8] studied the effects of temperature and different percentage of bitumen on the resistance to permanent deformation of HMA mixture and concluded that significant degree of confidence that the mix will not fail on the roadway due to permanent deformation can be achieved by simulating the laboratory test findings with field performance of mixes.

Tigdemir, M. [9] concluded that repeated loading axial permanent deformation test can satisfactorily be used in evaluating asphalt concrete mixtures permanent deformation and fatigue characteristics and both can be compared.

There is a critical need to develop such techniques, which can truly predict permanent deformation of asphalt concrete, being a material characterization problem. The scope of current study was therefore, limited to permanent deformation characteristics (permanent strain) of bituminous mixes. Uni-axial load strain or RLPD tests were performed on six mixes. Pulse counts, width and pulse period was kept constant during the test and percentage accumulative strain '$\varepsilon_p$' was measured under each specified condition.

## 3. OBJECTIVE

Following were the objectives of this study:

- To determine the effect of bitumen penetration grade on HMA (Hot Mix Asphalt) properties.
- To evaluate the performance of coarser gradation "01" and finer gradation "02" using three bitumen types.
- To compare the permanent deformation behavior (percentage of accumulated strain) of PMB with its base bitumen penetration grade '60/70' and "40/50" by varying temperature and stress levels.

## 4. TEST MATERIALS

### 4.1 Aggregates

Coarse and fine aggregates used for bituminous mixtures were obtained from a local lime stone quarry (Margalla). Mechanical and Physical properties of aggregates were determined as per AASHTO, BS and ASTM .

NHA in its general specifications [10] has specified two aggregate gradations, namely class "A" and "B", the coarser and finer respectively. Two gradations "01" and "02", within the envelope of class "A" being a commonly used gradation in the field were chosen for this study as reported in Table 1 and graphically plotted in Fig. 1.

Aggregate gradation "01" has relatively more percentage material retained on sieve number 19, 9.5 and 4.75mm, while gradation "02" has relatively more percentage material retained on sieve number 2.36, 0.30 and 0.075mm.

### 4.2 Bitumen

Two neat bitumen with penetration grade "60/70", "40/50" and one modified binder (PMB) were used. The base bitumen of PMB was penetration grade "60/70" modified with 1.6% Elvaloy® 4170 and 0.7% superphsophoric acid in Attock Laboratory, Pakistan. PG grading of PMB was developed using Attock Refinery penetration grade "60/70" bitumen and Elvaloy at Mathy Technology and Engineering Services [11] where in different trials were made to prepare a final blend that would be more suitable. Results of consistency tests on PMB matched with the penetration grade "40/50". Hence, it is designated as similar bitumen. Properties of all the three types of bitumen (two neat and one modified) have reported in Table 2.

## 5. EXPERIMENTAL DESIGN

### 5.1 Bituminous Mixtures Design

An Asphalt Institute [12] Marshall Method of Mix Design was adopted for the preparation of all the six mixtures and for the preparation of 10.2x6.3cm test specimens.

**TABLE 1. ADOPTED GRADATIONS AND SPECIFICATIONS**

| Sieve Size | | Combined Grading (Asphalt Wearing Course Class-A) | | | |
|---|---|---|---|---|---|
| Inch | mm | Gradation "1" | Gradation "2" | NHA Specifications (Class-A) | Asphalt Institute Gradation (1994) |
| 1 | 25.00 | 100 | 100 | 100 | 100 |
| 3/4 | 19.00 | 94 | 100 | 90-100 | 90-100 |
| 1/2 | 12.50 | - | - | - | - |
| 3/8 | 9.50 | 62 | 64.1 | 56-70 | 56-80 |
| #4 | 4.75 | 42 | 43.2 | 35-50 | 35-65 |
| #8 | 2.36 | 29 | 27.3 | 23-35 | 23-49 |
| #50 | 0.300 | 9 | 7.5 | 5-12 | 5-19 |
| #200 | 0.075 | 4.4 | 4.3 | 2-8 | 2-8 |

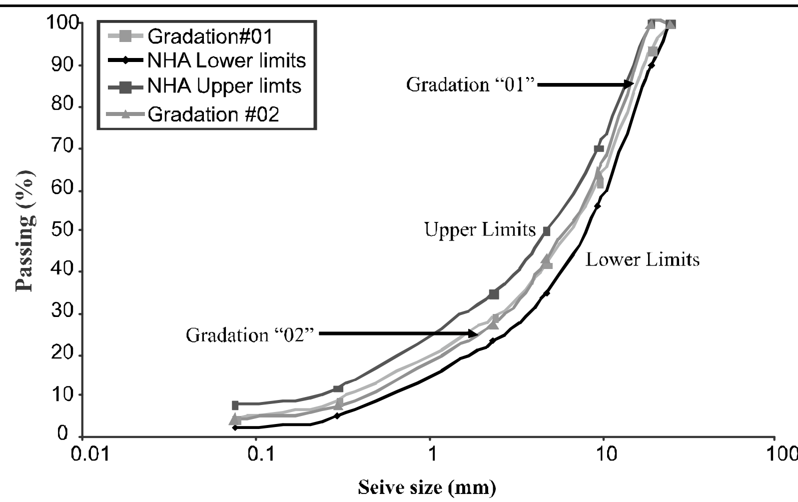


*FIG. 1. AGGREGATE GRADATION '01' AND '02' UNDER NHA CLASS 'A'*

Mixtures designations have been reported in Table 3. Optimum bitumen content, specific gravities, volumetric analysis, stability, flow, loss of stability and stiffness index, determined from each mix type have been reported in Tables 4-5.

### 5.2 Universal Testing Machine (UTM-5P)

UTM as shown in Fig. 2 is a series of closed loop servo control material testing machine designed to transmit energy to the HMA specimens using high pressure air acting on double sided piston (actuator). The actuator is

**TABLE 2. PROPERTIES OF DIFFERENT TYPES OF BITUMEN**

| No. | Description | PMB (1.6% Elvaloy 4170) | Bitumen Penetration Grade "60/70" | Bitumen Penetration Grade "40/50" |
|---|---|---|---|---|
| 1. | Type | Modified | Neat | Neat |
| 2. | Ring & Ball Softening Point | 58 | 49 | 56 |
| 3. | Penetration | 46 | 65 | 44 |
| 4. | Ductility @ 25$^0$C | 45 | 100 | 67 |
| 5. | Specific Gravity | 1.023 | 1.03 | 1.032 |

**TABLE 3. MIX TYPES**

| Mix Description | Gradation Type | Binder |
|---|---|---|
| 1a | 1 | PMA |
| 1b | 1 | 60/70 Penetration Grade |
| 1c | 1 | 40/50 Penetration Grade |
| 2a | 2 | PMA |
| 2b | 2 | 60/70 Penetration Grade |
| 2c | 2 | 40/50 Penetration Grade |

**TABLE 4. HOT MIX ASPHALT DESIGN PROPERTIES**

| Mix Types | Optimum AC Contents (%) | Stability (Kg) | Loss of Stability (%) | Flow (0.25mm) | Stiffness Index (Stability/Flow) |
|---|---|---|---|---|---|
| 1a (PMA) | 3.83 | 1378 | 11.00 | 10.80 | 128 |
| 1b (60/70) | 3.87 | 1305 | 14.30 | 11.00 | 119 |
| 1c (40/50) | 3.95 | 1356 | 12.70 | 10.50 | 129 |
| 2a (PMA) | 4.29 | 1335 | 08.90 | 09.80 | 136 |
| 2b (60/70) | 4.31 | 1298 | 11.00 | 11.30 | 115 |
| 2c (40/50) | 4.33 | 1314 | 10.50 | 10.50 | 125 |

**TABLE 5. HOT MIX ASPHALT DESIGN VOLUMETRIC PROPERTIES**

| Mix Types | Optimum AC Contents (%) | Gsb | Gmm | Gmb | VA (%) | VMA (%) | VFA (%) |
|---|---|---|---|---|---|---|---|
| 1a (PMA) | 3.83 | 2.650 | 2.522 | 2.373 | 5.90 | 13.90 | 58.00 |
| 1b (60/70) | 3.87 | 2.650 | 2.515 | 2.371 | 5.70 | 13.99 | 59.00 |
| 1c (40/50) | 3.95 | 2.650 | 2.514 | 2.370 | 5.70 | 14.10 | 60.00 |
| 2a (PMA) | 4.29 | 2.662 | 2.520 | 2.395 | 4.96 | 13.90 | 64.00 |
| 2b (60/70) | 4.31 | 2.662 | 2.516 | 2.386 | 5.17 | 14.23 | 63.70 |
| 2c (40/50) | 4.33 | 2.662 | 2.515 | 2.384 | 5.20 | 14.32 | 63.70 |

mechanically coupled to the specimen through a reaction loading frame. The Flow of air pressure is controlled by a servo valve where in small electric currents are used to open and close the control spool of the valve. These transducers convert mechanical movement into standard electronic signals and via CDAS (Control and Data Acquisition System) displays output on the personal computer. The transducers signals are also used to control the system [13].

### 5.3 Repeated Load Permanent Deformation Test

In UTM-5P, strain test applies a repeated load of defined magnitude and cyclic duration to specimens, where in '$\varepsilon_p$' correlates mix permanent deformation behavior with rutting potential in the field. For the current study, a static conditioning stress and conditioning time was applied prior to commencement of actual test. Conditioning time and conditioning stress were kept 100 sec and 10 kpa respectively. Following the conditioning period and stress, a fixed twenty seconds time of delay was programmed (by default), where the applied stress was set to zero.

*FIG. 2. UNIVERSAL TESTING MACHINE (UTM-5P)*

Consequently, the specimens were subjected to repeated pulse loading of 1800 cycles at 100, 300 and 500 kpa, which closely simulate with the field loading conditions in Pakistan. The applied load varies in short pulse followed by a rest period. Pulse width and pulse period were kept 500 milli-seconds and 2000 milli-seconds respectively, according to the reference standard [13]. The magnitude of the loading stress and the timing width of the pulse applied to the specimen during a test were directly controlled by the "test loading stress" and "pulse width" parameters in the test set up and control edit screen. The minimum standard force (20N) and set by default ensured that the loading actuator would not be lifted off the specimen between pulse applications [13]. As pulse loading continued, the permanent deformation in terms of accumulated strain was measured using two LVDTs (Linear Variable Displacement Transformers).

### 5.4 Testing Methodology

For each stress level, three specimens were tested at 25, 40 and 55$^0$C, which cover typical summer temperature range in Pakistan. Samples were evaluated for 54 test conditions (27 for each type of gradation) and total 162 specimens were prepared.

## 6. RESULTS AND DISCUSSION

The results of '$\varepsilon_p$' have been tabulated in Table 6 and graphically plotted in Fig. 3 to make a comparison among gradations, bitumen types, temperatures and stress levels. Results of permanent strain have shown correlations among all the four variables used in this experimental study i.e. aggregate gradation, bitumen types, temperatures, stress levels. It was also observed that bitumen type has relatively miner effects on the '$\varepsilon_p$' of coarser and finer mixes at low temperature (25$^0$C). At high stress (500 kpa) and temperature 55$^0$C, permanent strain of course graded mixtures showed better results. On the other mixtures with modified bitumen showed better results. Among all the variables, temperature was observed to be the most sensitive parameter of permanent deformation.

**TABLE 6. PERCENTAGE ACCUMULATED STRAIN OF MIXES**

| No. | Temperature ($^0$C) | Stress (KPa) | Percentage Accumulated Strain ($\varepsilon_p$) of Mixes | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 1a | 1b | 1c | 2a | 2b | 2c |
| 1. | 25 | 100 | 0.193 | 0.281 | 0.183 | 0.286 | 0.403 | 0.315 |
| 2. | 25 | 300 | 0.399 | 0.564 | 0.375 | 0.516 | 0.572 | 0.493 |
| 3. | 25 | 500 | 0.616 | 0.686 | 0.592 | 0.907 | 0.958 | 0.926 |
| 4. | 40 | 100 | 0.332 | 0.424 | 0.389 | 0.540 | 0.590 | 0.536 |
| 5. | 40 | 300 | 0.547 | 0.742 | 0.666 | 0.609 | 0.774 | 0.676 |
| 6. | 40 | 500 | 0.881 | 0.990 | 0.946 | 0.989 | 1.057 | 0.995 |
| 7. | 55 | 100 | 0.438 | 0.577 | 0.526 | 0.833 | 0.647 | 0.747 |
| 8. | 55 | 300 | 1.114 | 1.164 | 1.124 | 1.052 | 1.172 | 1.058 |
| 9. | 55 | 500 | 1.242 | 1.266 | 1.247 | 1.320 | 1.441 | 1.375 |

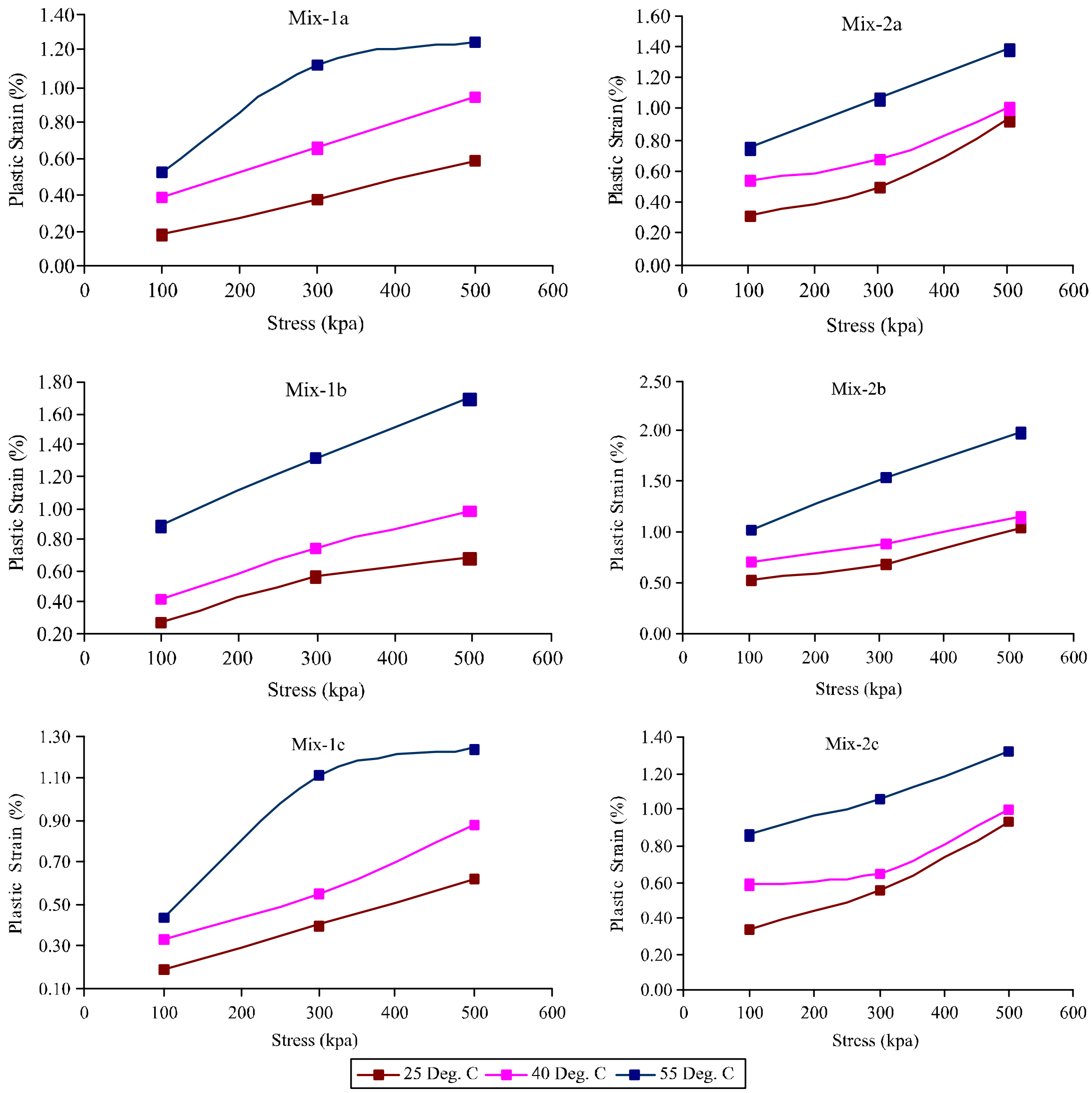


*FIG. 3. INFLUENCE OF TEST TEMPERATURES AND STRESS LEVELS ON '$\varepsilon_p$' OF ASPHALT MIXTURES*

## 7. CONCLUSIONS

Analysis of test data files revealed that RLPD is an important test to predict mixtures probable rut potential in the laboratory. However, based on this research study following conclusion can be drawn.

(i) Optimum bitumen content of mixes with "PMB" was comparatively less than the other type's of mixes.

(ii) Coarse graded mixes performed better at lower bitumen content as compared to fine graded mixes.

(iii) It was observed that at low temperature and stress level, '$\varepsilon_p$' was same for both gradation with "PMB" and "40/50", but at higher temperature and stress level, "PMB" showed less percentage of accumulated strain.

(iv) Overall performance of mix with penetration grade "60/70" bitumen was lower as compared to penetration grade "40/50" and PMB.

(v) Percentage accumulated strain at $25^0$C increased linearly in coarse graded mixes and curve-linear (concave upward) in fine graded mixes.

(vi) Increase in '$\varepsilon_p$' at $40^0$C showed almost identical trends in both types of mixes.

(vii) Fine graded mixtures showed more '$\varepsilon_p$' at $55^0$C than coarser one.

(viii) Fine and course graded mixtures have similar trend of '$\varepsilon_p$' at stress level 300 kpa.

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