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Evaluation of Rutting in HMA Mixtures Using Uniaxial Repeated Creep & Wheel Tracker Tests

[1]Imran Hafeez, [2]Mumtaz Ahmed Kamal, [3]Muhammad Waseem Mirza

1. Assistant Professor, Department of Civil Engineering, University of Engineering & Technology, Taxila, Pakistan E-mail: imranhafeez783@yahoo.com

2. Professor, Department of Civil Engineering, University of Engineering & Technology, Taxila, Pakistan. E-mail: drmakamal@yahoo.com

3. Professor, Department of Transportation Engineering & Management, University of Engineering & Technology, Lahore, Pakistan. E-mail: mw.mirza@hotmail.com

Abstract

Permanent deformation of asphaltic concrete depends on temperature, rate of loading and state of stress and significantly increases above 40 ^oC. The deformation behavior of finer to coarser hot-mix asphalt (HMA) mixtures was investigated in the laboratory by varying stress level from 100 to 500 kPa at 40 ^oC & 55 ^oC. Uniaxial repeated creep and wheel tracker tests were carried out at the specified conditions and the results were correlated to seek relationships between test methods. Subsequently, shift factors and a correlation between the test methods are proposed to guide pavement engineers in the selection of rut resistant mixtures in future. The results show that intercept coefficients vary in a narrow range and an average shift of 0.48 makes both the tests data on a straight line. Uniaxial repeated load strain test do not show a clear ranking of the mixtures at the specified temperatures and the stress conditions. The slope of linear relationship between the tests reduces with an increase in temperature and stress level.

Key Words: *Permanent deformation; wheel tracker; creep test; regression analysis*

1. Introduction

Over the past twenty years; road traffic (both passenger and freight) has grown significantly in Pakistan. Higher axle loads and repetitions have resulted in premature rutting of flexible pavements. Rutting, in the form of shear flow is a typical distress that mainly attributed to increased tire pressure, high temperature and heavy axle loads. Consequently, National Highway Authority (NHA), Pakistan is facing challenges due to frequent pavement failures, high maintenance costs and poor riding quality of pavements [1]. Laboratory characterization of asphalt mixtures is thus very important [2]. True prediction of asphalt material behaviors a5d their precise selection on the basis of laboratory performance can be one of the solutions towards this chaotic problem.

If an asphalt material is loaded with a stress that is above the flow strength of the material, at that temperature the material will start to deform, known as creep [3]. Rutting, also called as permanent deformation or creep in asphalt (flexible) pavements, usually consists of longitudinal depressions in the wheel paths, which are an accumulation of small amounts of unrecoverable deformation caused by each load application [4]. It has been reported that rutting increases with an increase in temperature even under well controlled loading conditions and asphalt mixtures built up more resistance to flow during the process of deforming under repetitive loading [5].

At low temperature (25^oC) and stress level (100 kPa) the coarser mix were less susceptibility to permanent deformation as compared to finer mix, where as at high temperature and stress levels, a shift in behavior of both the mixes have been observed [6]**.** Numerous models have been used to relate plastic strain accumulation to the number of load repetitions [7]

This study aims to evaluate the effects of cyclic loading on accumulative strain using uni-axial repeated creep test by using Universal Testing Machine (UTM-5P) and standard wheel tracker test at the standard frequency of loading. Different methodologies have been proposed for characterizing HMA mixtures prior to their selection in the field.

2. Testing Materials

Coarse and fine aggregates were obtained from a local lime stone quarry (Margalla), located near Islamabad, which is one the best mechanically fractured aggregate producing quarry in Pakistan. Mechanical and physical properties of aggregates were determined as per AASHTO, BS and ASTM standards. No rounded particle or river bed gravel was used in the experimental work. The Los Angeles abrasion value, sodium sulphate soundness and percentage absorption of specimen aggregate were 23%, 3.32% and 0.88% respectively. NHA general specifications [8] has specified two aggregate gradations for asphalt wearing course, namely ‘class-A’ and ‘class-B’, the coarser and finer gradations, respectively.

Two gradations relatively ‘coarser’ and ‘finer’, within the envelope of NHA class ‘A’ gradation, were prepared for this study as reported in Table 1. Two neat bitumen with penetration grade ‘60/70’ & ‘40/50’ and one polymer modified binder (PMB) with base asphalt ‘60/70’ were used. The base binder i.e. Pen 60/70 grade was modified with 1.6% Elvaloy reactive ter-polymer and 0.7% super-phsophoric acid in Attock Laboratory, Pakistan.

3. Experimental Design

Marshall Method of Mix Design [9] was adopted for the preparation of six HMA mixtures as shown in Table 2. Mixtures were designed at optimum asphalt contents, air voids ranging from 4 to 6 percent and minimum voids in mineral aggregates of 13%, whereas stiffness index (ratio of stability to flow) of the six mixes ranged from 115 to 136.

The controlled stress test in UTM-5P applies 1800 block (square) repeated load pulse with a pulse width and pulse period of 500 milli-seconds and 2000 milli-seconds respectively, to the specimens. As pulse loading continued as shown in Figure 1a, the permanent deformation in terms of accumulated strain as shown in Figure 1b was measured using two Linear Variable Displacement Transformers (LVDTs). Percentage accumulative strain was measured as response to repeated pulses to correlate mix permanent deformation behavior with rutting potential in the field [10]. The percentage accumulative strain obtained from the test correlates permanent deformation behavior or creep with rutting potential of HMA mixture in the field. Three stress levels i.e. 100, 300 and 500 kPa were selected to simulate loading in the field.

Wheel Tracker (WT) as shown in Figure 2, assesses the resistance to rutting of asphaltic material under conditions which simulate the effects of traffic and environment by measuring relative percentage reduction in thickness of the specimen in the wheel path. A loaded wheel (700 ± 20 N) tracked with simple harmonic motion through a distance of 305 mm on specimens under specified conditions of speed (53 passes per minute) and temperatures (40, 55^{o}C). Development of the rut was monitored with LVDT and the rut depth was quantified as rut resistance of mixes at the end of the test [11].

Marshall compacted specimens (10.2 cm diameter x 6.3 cm height) for creep test and roller compacted specimens (30.5cm x 30.5cm wide x 5.0cm deep) for wheel tracking tests were prepared at design air voids & were tested in triplicate at 40 ^{o}C & 55 ^{o}C (36 specimens on WT test & 108 specimens on creep test). The results have been compiled in terms of accumulative strain and rut depth as reported in Table 3 &4.

4. Results and Discussion

Regression Analysis

The results of percentage accumulated strain were plotted on a log-log scale against load cycles. Regression Coefficients i.e intercept coefficient “a” and slope coefficient “b” using the following basic power model.

$$\varepsilon_p = aN^b \qquad (1)$$

Where, ‘ε_p’ is the permanent strain (rut value), ‘N’ is the number of load application and ‘a’ is the intercept coefficient. A typically plot of the above model is shown in Figure 3 (Hafeez et al, 2010). Equation 2 shows the above relation in Log form.

$$\log \varepsilon_p = \log a + b \log N \qquad (2)$$

Mixes were ranked using intercept coefficient ‘a’ in descending order. The results of Intercept coefficient for uniaxial load strain test and WT are shown in Table 5 & 6. It can be observed that ‘a’ increases with an increase in stress level, irrespective of aggregate gradations, bitumen types, mix types, and test temperatures. The intercept coefficient ‘a’ of mixes under all temperature and stress conditions in creep and WT test ranges from 4.73 - 5.48 and 4.34 - 5.35 respectively. Results of Table 5 & 6 clearly show that ‘a’ varies in a narrow range of 4.34 to 5.48 for both the test procedures.

Further, mixes were ranked based on ‘a’ value to observe the best possible options of mix performance under given temperatures for both the tests and tabulated in Table 7 and 8. It is difficult to conclude mixes ranks using intercept coefficient in the creep test. However, one can draw a conclusion from Table 7 that mixes with PMB has best ranking at high temperature (55 ^{o}C). Increase in stress levels has relatively minor effects on permanent strains and hence ‘a’ value. However, significant influence of temperature on the regression constant has been observed.

Table 8 shows that increase in temperature from 40-55^{o}C has affected only the position of mix ‘2c’ and ‘1b’ from rank 5 to 3 respectively. The reasons may be that Pen 40/50 grade is harder grade than Pen 60/70 grade and it showed lower intercept value at 55 ^{o}C. Intercept coefficients of mixes with coarser gradation (1a, 1b & 1c) have lower value than finer mixes (2a, 2b & 2c) in wheel tracker test.

Shift Factor Computations

Permanent strain obtained from creep test was converted to rut depth using layer strain method.

$$RutDepth = \sum_{i=1}^{N} \left[\varepsilon_p(i) \times h_i\right] \qquad (3)$$

Where '*i*' remains as one, N is the total number of load repetitions; 'ε_p' is the permanent strain and 'h_i' the thickness of Marshall Specimens (63mm). Rut depth obtained from the above method, was plotted on log-log scale after multiplying "ε_p" with one million in order to obtain positive values and straight line trends. Data obtained from both the tests were plotted graphically in Figure 4, and shift factors were determined. Figure 4 shows that master curve is almost a straight line and plots of creep test can be shifted to that of WT test with a shift factor ranging from 0.2 to 0.75, and an average value of 0.48.

4.3 Correlations between Repeated Load Strain Test and Wheel Tracker Test

Figure 5 & 6 show correlations in terms of rut depth, developed between both the tests. It can be observed from Figure 5 & 6 that relationship can be developed reasonably between both the test types to ascertain mixture's rut potential. Also, range of data variation reduces with the increase in temperature and stress levels. Wheel tracker specimens being confined in the test mould produced less rate of increase in permanent strain (rut depth) than unconfined uniaxial repeated creep test.

Table 1: Aggregate gradations

Sieve Size		Combined grading (Asphalt Wearing Course Class-A)			
		Gradation "1"	Gradation "2"		
Inch	mm	Targeted values (% Passing)	Targeted values (% Passing)	NHA Specifications 'Class-A'	Asphalt Institute Gradation (1994)
1	25.00	100	100	100	100
3/4	19.00	90	100	90-100	90-100
1/2	12.50	-	-	-	-
3/8	9.50	56	69.1	56-70	56-80
#4	4.75	38	48.2	35-50	35-65
#8	2.36	25	30.3	23-35	23-49
#50	0.300	5	10.5	5-12	5-19
#200	0.075	3.4	5.3	2-8	2-8

Table 2: Mixture's Types

Mix Description	Gradation Type	Binder Type
1a	Coarser	PMA
1b	Coarser	60/70 Pen. grade
1c	Coarser	40/50 Pen. grade
2a	Finer	PMA
2b	Finer	60/70 Pen. grade
2c	Finer	40/50 Pen. grade

Table 3: Permanent strain measured in uniaxial creep tests

Sr. No.	Temp. (^oC)	Stress (kPa)	Plastic Strain (ε_p) values (%)					
			PMA-Coarser Mix (1a)	60/70-Coarser Mix (1b)	40/50-Coarser Mix (1c)	PMA-Finer Mix (2a)	60/70-Finer Mix (2b)	40/50-Finer Mix (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	0.834	0.647	0.747
8	55	300	1.114	1.164	1.126	1.052	1.172	1.058
9	55	500	1.242	1.266	1.247	1.320	1.441	1.375

Table 4: Measured rut depth of mixes

Sr. No.	Temp. (^oC)	Measured Rut Depth (mm) of Mixes					
		PMA-Coarser Mix (1a)	60/70-Coarser Mix (1b)	40/50-Coarser Mix (1c)	PMA-Finer Mix (2a)	60/70-Finer Mix (2b)	40/50-Finer Mix (2c)
1	25	2.74	3.90	2.82	4.53	5.99	4.60
2	40	6.20	9.99	6.62	10.86	14.60	12.08
3	55	8.53	15.20	11.61	17.80	23.40	19.00

Table 5: Intercept coefficient of mixes in repeated creep test

Temp. (^oC)	Stress Level	Gradation "01"			Gradation "02"			Coefficient of Variance
		PMA-Coarser Mix (1a)	60/70-Coarser Mix (1b)	40/50-Coarser Mix (1c)	PMA-Finer Mix (2a)	60/70-Finer Mix (2b)	40/50-Finer Mix (2c)	
	100	4.77	4.73	4.93	5.06	5.15	4.91	1.22
40	300	5.15	4.89	5.15	5.14	5.13	5.07	0.74
	500	5.25	5.07	5.25	5.36	5.31	5.10	0.78
	100	4.73	4.82	4.82	4.78	5.02	4.83	0.74
55	300	4.82	5.06	4.97	4.83	5.07	4.99	0.83
	500	4.98	5.32	5.09	5.05	5.48	5.32	1.39

Table 6: Intercept coefficient of mixes using WT test

Sr. No.	Temperature (^oC)	Mix -1a	Mix-1b	Mix-1c	Mix-2a	Mix-2b	Mix-2c
1	40	4.81	4.81	4.78	4.98	5.27	5.17
2	55	4.77	5.12	4.34	5.12	5.35	5.03

Table 7: Ranking of mixes for uni-axial repeated creep test

Sr. No.	Temp. (^oC)	Stress (kPa)	Ranking of mixes					
			1st	2nd	3rd	4th	5th	6th
1	40	100	1b	1a	2c	1c	2a	2b
2	40	300	1b	2a	1a	2a	1a	1c
3	40	500	1b	2c	1c	1c	2b	2a
4	55	100	1a	2a	1c	1b	2c	2b
5	55	300	1a	2a	1c	2c	1b	2b
6	55	500	1a	2a	1c	2c	1b	2b

Table 8: Ranking of mixes for WT test

Sr. No.	Temp. (^oC)	Ranking of mixes					
		1st	2nd	3rd	4th	5th	6th
2	40	1c	1a	1b	2a	2c	2b
3	55	1c	1a	2c	2a	1b	2b

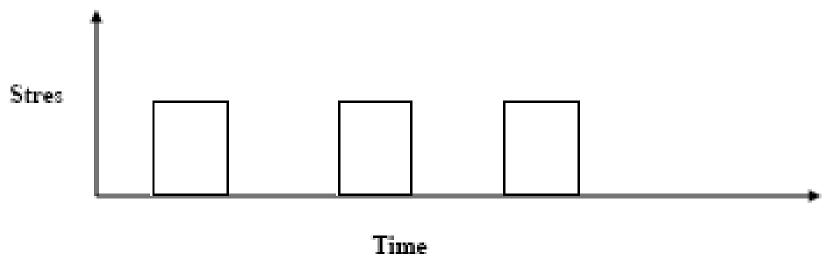


Fig. 1a: The Loading pulse wave form in the uniaxial repeated creep test

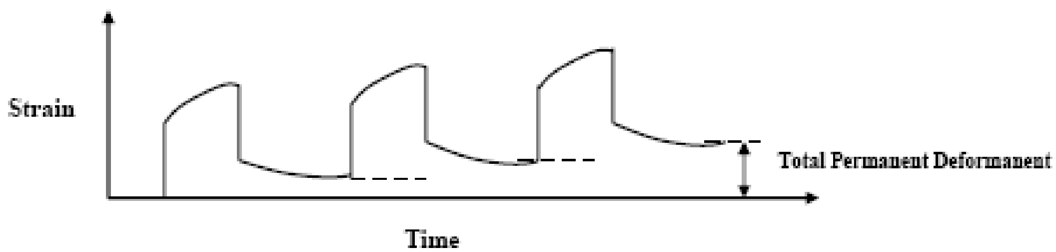
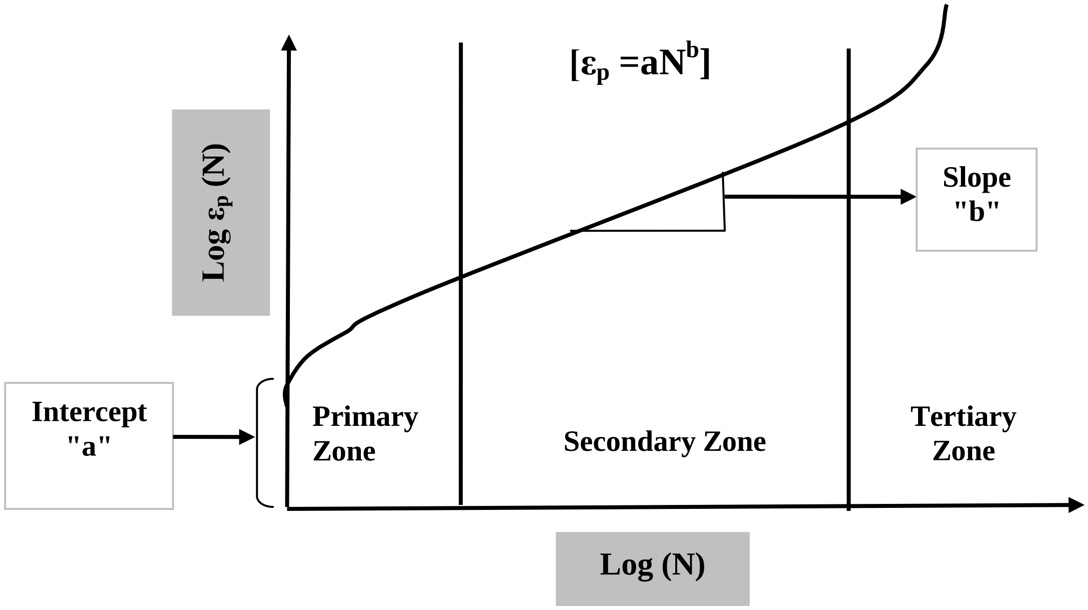


Fig. 1b: The Strain wave form in the uniaxial repeated creep test

Fig. 2: Cooper wheel tracker (After Cooper, 2006)



x

Fig. 3: Log-log relationships between load repetition and permanent strain

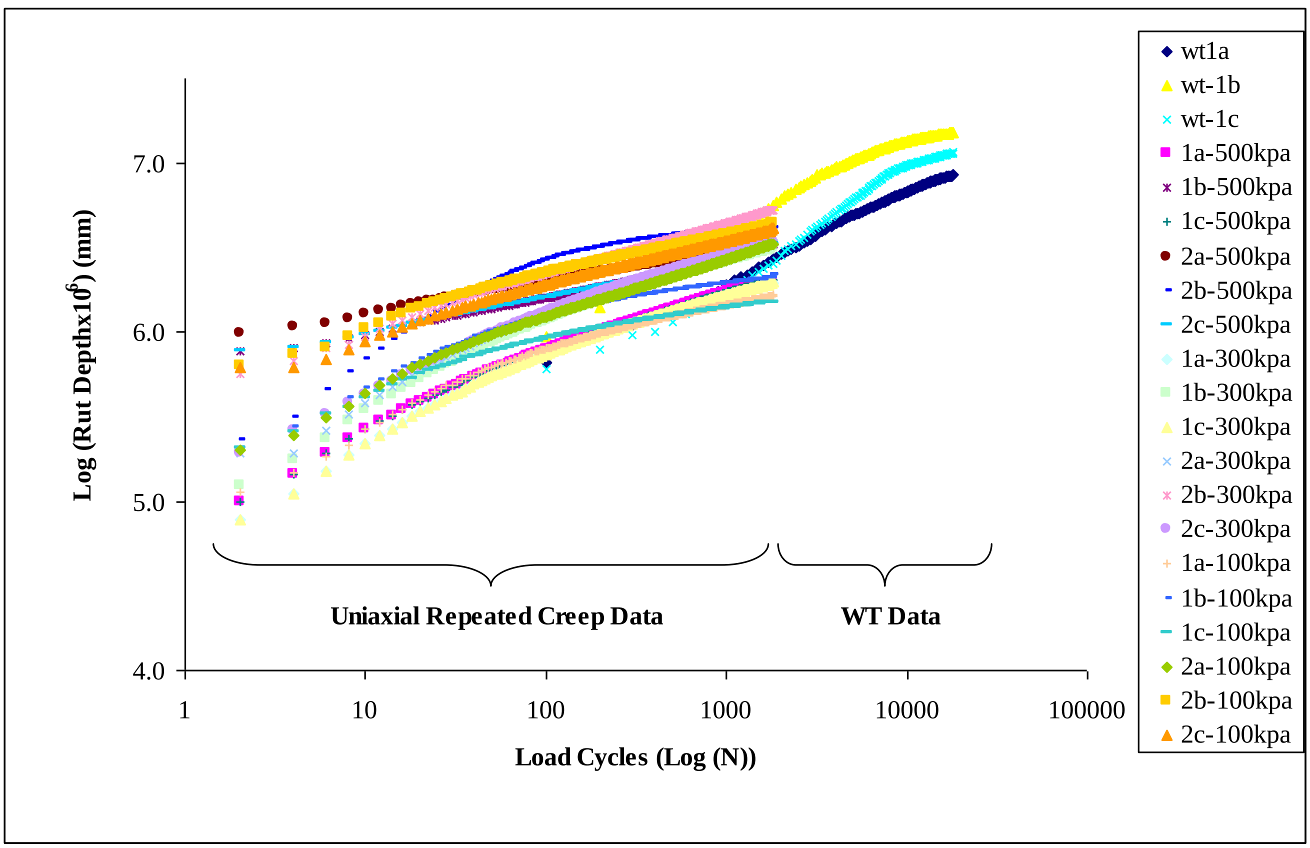


Fig. 4: Shift of Uniaxial Repeated Load test data to Wheel Tracker data

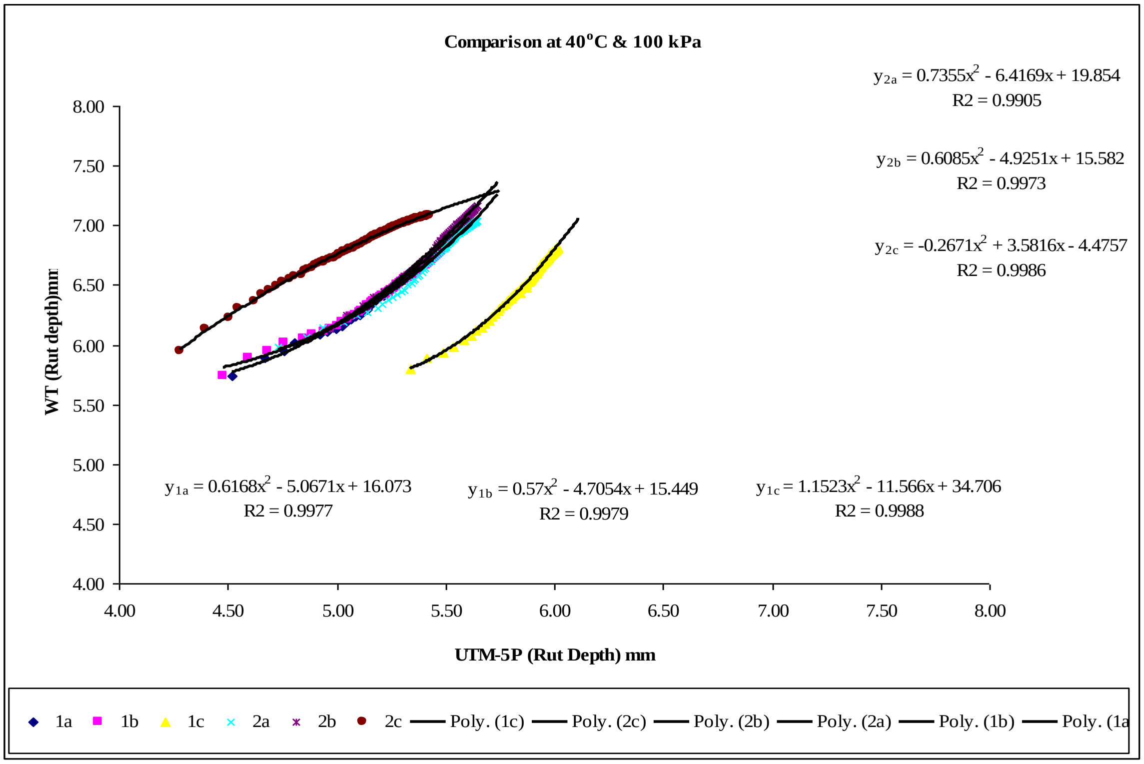

Comparison at 40°C & 100 kPa
y2a = 0.7355x2 - 6.4169x + 19.854
R2 = 0.9905
y2b = 0.6085x2 - 4.9251x + 15.582
R2 = 0.9973
y2c = -0.2671x2 + 3.5816x - 4.4757
R2 = 0.9986
y1a = 0.6168x2 - 5.0671x + 16.073
R2 = 0.9977
y1b = 0.57x2 - 4.7054x + 15.449
R2 = 0.9979
y1c = 1.1523x2 - 11.566x + 34.706
R2 = 0.9988
WT (Rut depth)mm
UTM-5P (Rut Depth) mm
1a 1b 1c 2a 2b 2c Poly. (1c) Poly. (2c) Poly. (2b) Poly. (2a) Poly. (1b) Poly. (1a

Fig. 5(a)

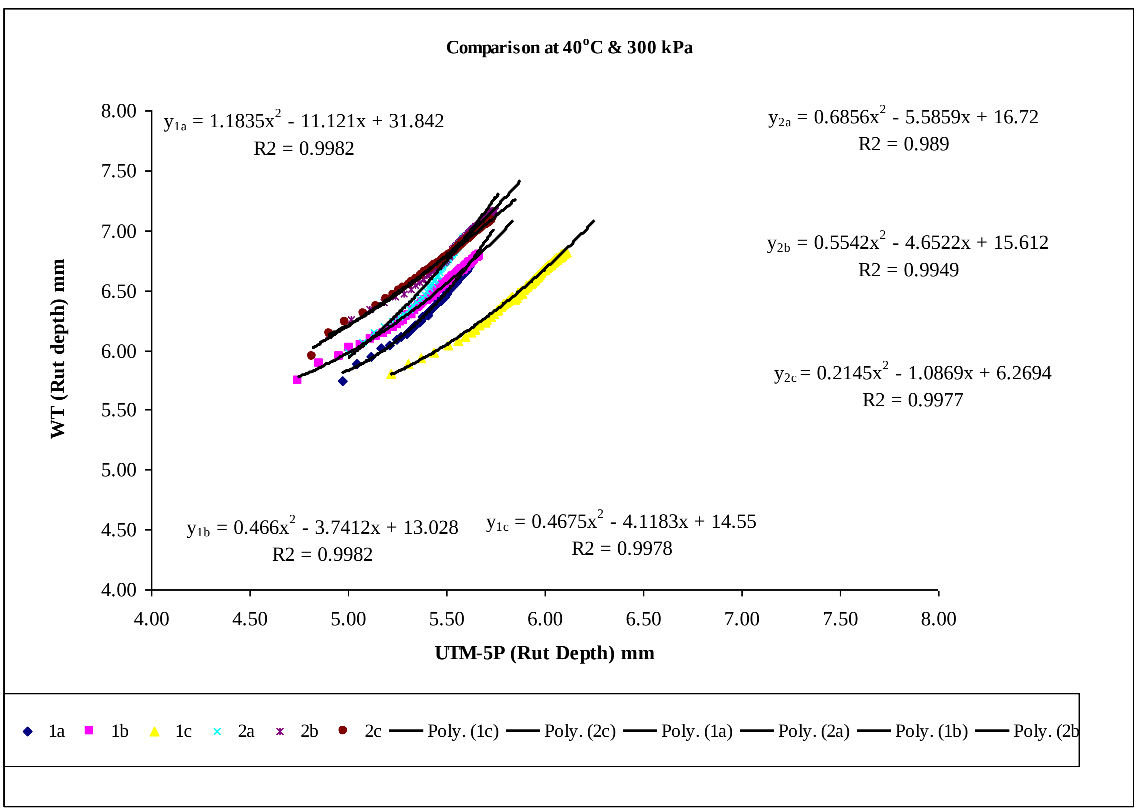

Comparison at 40°C & 300 kPa
y1a = 1.1835x2 - 11.121x + 31.842
R2 = 0.9982
y2a = 0.6856x2 - 5.5859x + 16.72
R2 = 0.989
y2b = 0.5542x2 - 4.6522x + 15.612
R2 = 0.9949
y2c = 0.2145x2 - 1.0869x + 6.2694
R2 = 0.9977
y1b = 0.466x2 - 3.7412x + 13.028
R2 = 0.9982
y1c = 0.4675x2 - 4.1183x + 14.55
R2 = 0.9978
WT (Rut depth) mm
UTM-5P (Rut Depth) mm
1a 1b 1c 2a 2b 2c Poly. (1c) Poly. (2c) Poly. (1a) Poly. (2a) Poly. (1b) Poly. (2b

Fig. 5(b)

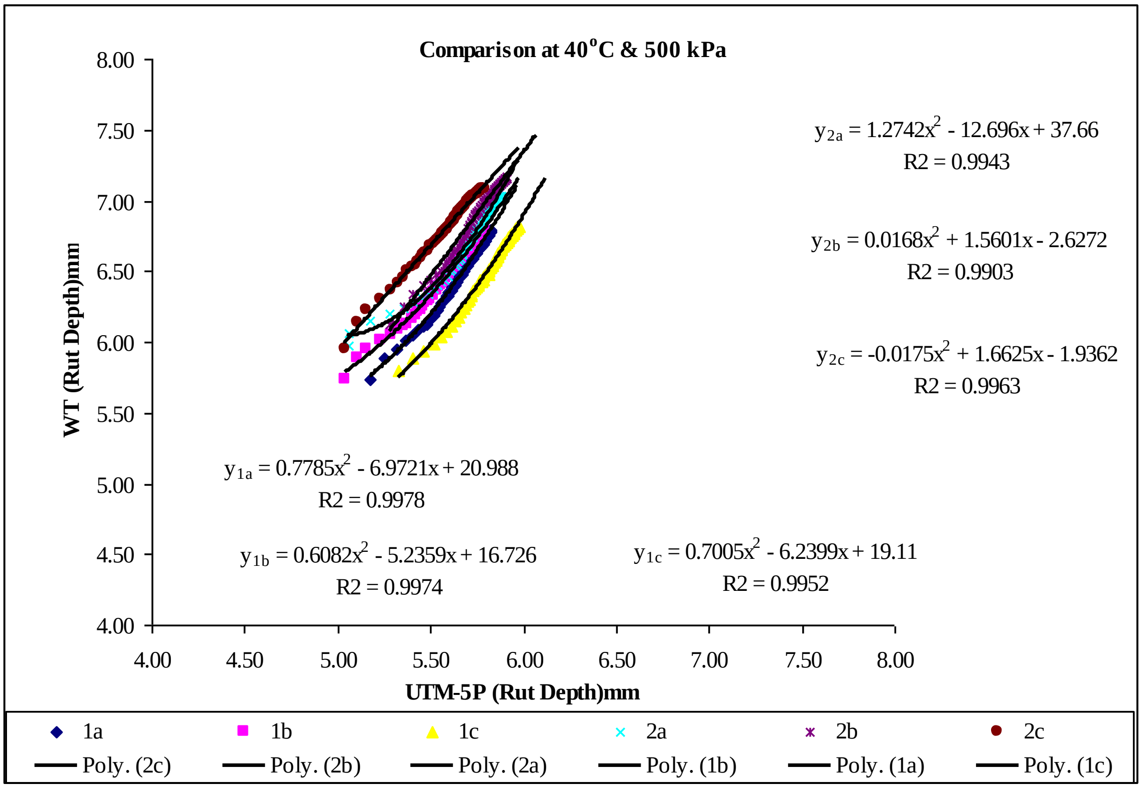


Fig. 5(c)

Figs. 5a, 5b, 5c: Correlations between repeated load strain test and wheel tracker test 40 °C.

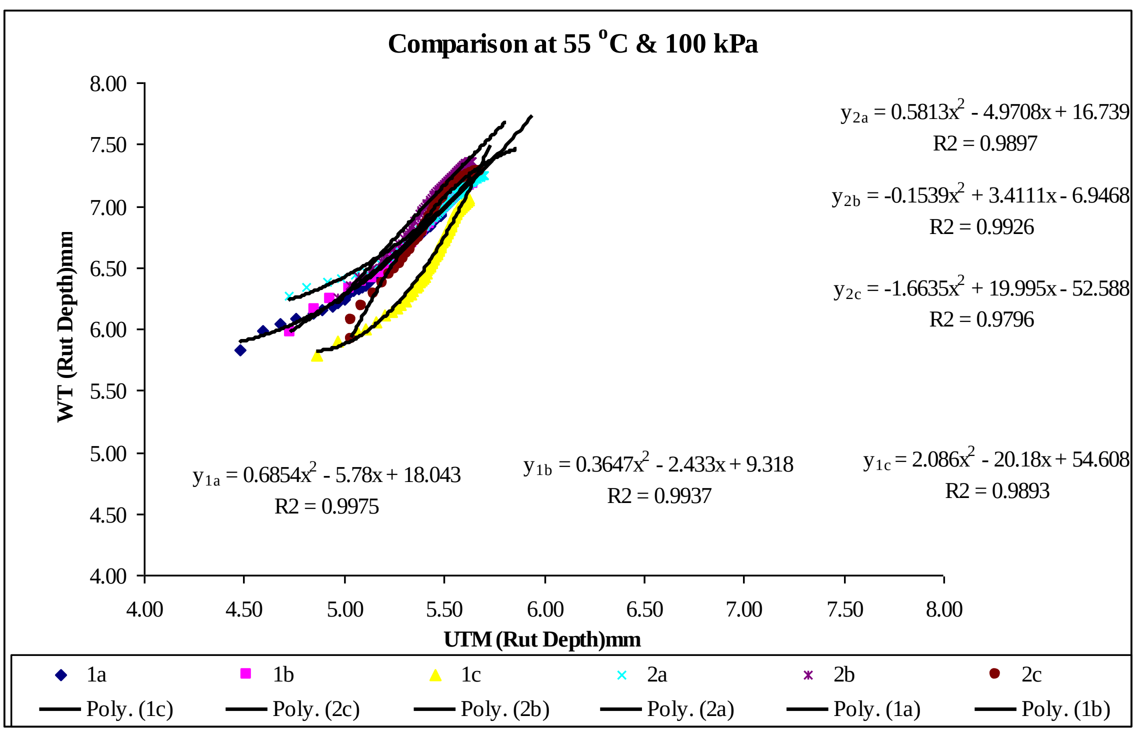


Fig. 6(a)

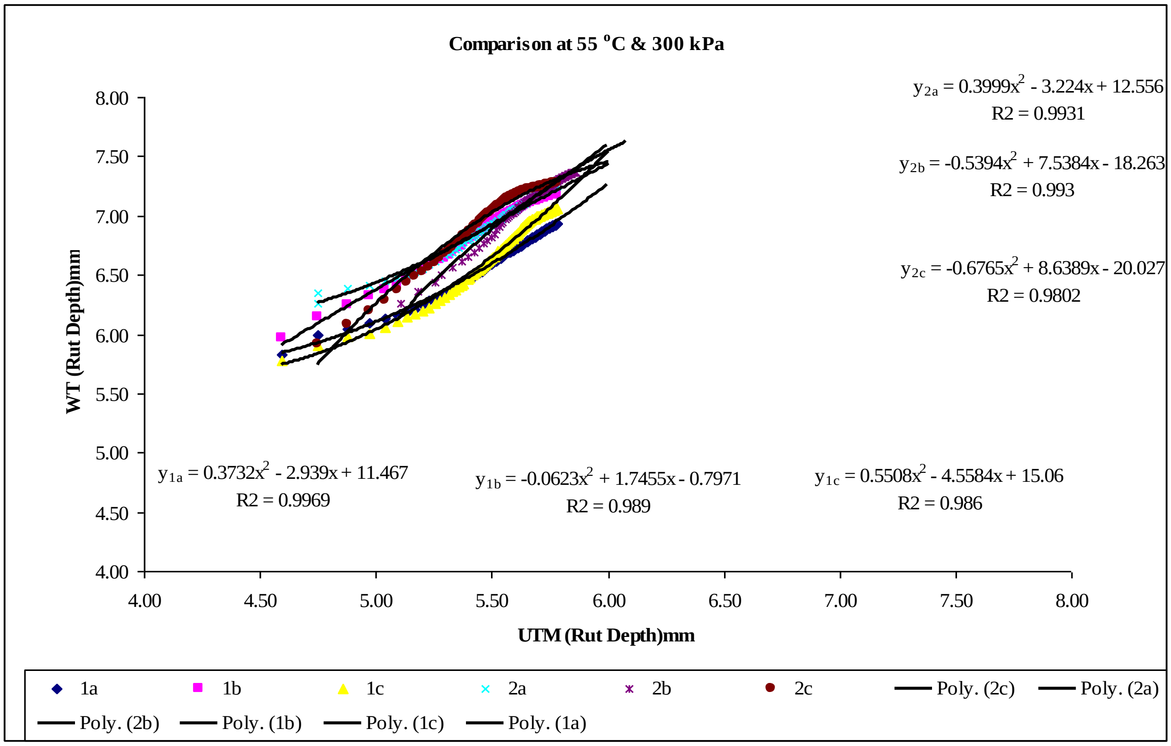


Fig. 6(b)

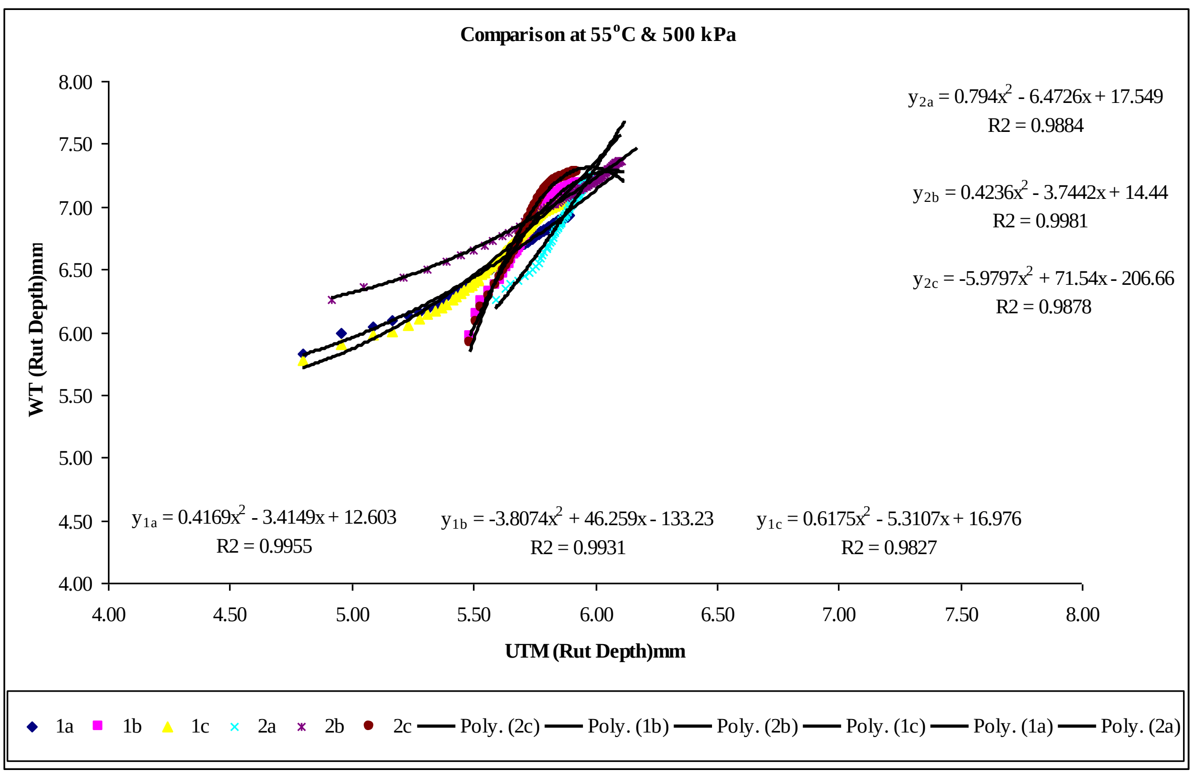


Fig. 6(c)

Figs. 6a, 6b, 6c: Correlations between repeated load strain test and wheel tracker test 55 °C

5. Conclusions

The objectives of the study was to evaluate HMA Mixture's for rutting using two commonly known tests (uniaxial repeated creep and wheel tracker test), to predict permanent deformation resistance or rutting of mixtures at elevated temperatures. Creep in the mixtures is a result of a stress that is above the flow strength of the material, at that temperature the material will start to deform. Also, it suggests criteria of selecting the HMA mixtures based on different coefficients. Following conclusions can be drawn from the above results.

1. Rutting can be predicted from any of the test method and can be compared reasonably with one another.
2. Ranking helps in identifying HMA mixture's performance under different loading and temperature conditions. However, uniaxial repeated creep test does not provide a clear indication of mixture's ranks.
3. Shift factor is a useful index. The results and plots of creep tests can be shifted to that of WT test with an average shift factor of 0.48.

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