# Prediction of permanent strain from resilient modulus for low asphalt content mixes in a Mechanistic-Empirical Model

I. Hafeez
*Department of Civil Engineeirng, Universty of Engineering & Technology, Taxila, Pakistan*

M A. Kamal
*Department of Civil Engineering, University of Engineering & Technology, Taxila, Pakistan*

Shahab Khanzada
*Pavement Specialist, National Highway Authority, Ministry of Communication, Islamabad*

ABSTRACT: Permanent deformation commonly known as rutting in flexible pavements due to shear flow can be predicted by statistical computation of Mechanistic-Empirical Models. It requires comprehensive laboratory investigations on various parameters that influence the asphalt mixture properties. Six asphalt mixtures, three binders and two aggregate gradations (typically used for asphalt wearing course in Pakistan) were. Samples were tested at three temperatures i.e. 25, 40 & 55°C and three stress levels i.e. 100, 300 and 500 kPa. The results of the study carried out at Taxila Institute of Transportation Engineering, Pakistan showed that permanent deformation of asphalt concrete mixtures in terms of permanent strain can be related with the resilient modulus. It was also observed that permanent strain is a function of stress level, temperature, resilient modulus and stiffness index. Regression model showed an excellent agreement between the predicted and the measured permanent strain.

KEY WORDS: Pavement, permanent deformation, resilient modulus, stiffness index.

## 1 LITERATURE REVIEW

Permanent deformation (rutting) in asphalt pavements mainly occurs due to densification and shear deformation of asphalt concrete. Shear deformation occurs with no change in volume, i.e., it is distortional, while densification is purely a volume change phenomenon (Paterson, 1987). Extensive studies have been conducted using a number of laboratory and field test methods to estimate accurate rutting prediction [NCHRP 2004]. Fujie et al (2004) studied the relationship between the number of load repetitions and permanent deformation and suggested to include three distinct stages, namely the primary, secondary and tertiary stages.

Kamal et al (2005) studied the insitu behavior of asphalt concrete with and without PMA under same temperature and loading conditions and compared resilient modulus and creep stiffness of both type of mixes, using the indirect tensile strength test (ASTM D4123) and repeated load uniaxial stain test. A drastic reduction of about 85% in resilient modulus has been reported by an increase in temperature from 25 to 40°C.

Ziari et al (2007) studied the effects of temperature and different percentage of bitumen on the resistance to permanent deformation of HMA mixture and concluded that the mix will not fail on the roadway due to permanent deformation. This can be achieved with significant degree of confidence by simulating the laboratory test findings with field performance of mixes. The prediction of asphalt mixture's rutting is a complex issue. [Anderson 2003, Shah 2004, Faheem 2005].

The current Mechanistic Empirical Pavement Design Guide (MEPDG) incorporates following power model for generating rutting predictions for asphalt concrete (Stephen et. al. 2007). Following rutting model developed from laboratory unconfined repeated load permanent deformation tests in MEPDG:

$$\frac{\varepsilon_p}{\varepsilon_r} = a_1 T^{a_2} N^{a_3} \tag{1}$$

Where, $\varepsilon_p$, & $\varepsilon_r$, are the plastic and resilient/elastic strains respectively, at N repetitions of haversine unconfined repeated loading, T is the temperature and $a_i$ is the non linear regression coefficients.

Su et al (2008) determined the shear deformation of asphalt mixtures by applying laboratory wheel tests under different temperature, loading and for various thicknesses of asphalt specimens. Static Uniaxial Penetration Test and Finite Element Methods have been used in the analysis and modifications of already developed rutting prediction models.

All studies were carried out to predict permanent deformation in asphalt mixture by exploring various influencing factors. Two important parameters of asphalt mixtures i.e. resilient modulus (elastic component) & permanent strain (plastic component) have been investigated in the current study. An effort has also been made to relate plermanent strain of asphalt mixture with the elastic strain (in terms of resilient modulus) measured under uniaxial repeated creep test.

## 2 OBJECTIVE

The main objective of this study was to develop a regression model for the prediction of permanent strain from the measured resilient modulus of asphalt mixtures, subjected to repeated creep test.

## 3 METHODOLOGY

Six asphalt mixtures using three types of binders ['60/70' & '40/50'] penetration grade and one polymer modified asphalt [PMA with base asphalt '60/70' & Elvaloy Terpolymer], and two aggregate gradations as per National Highway Authority (1998) specifications (coarser and finer as shown in Figure 1) were prepared by Marshall Method of Mix Design. Single source of aggregate (Margalla crush quarry located near Islamabad, Pakistan) and two sources of bitumen (National Refinery & Attock Refinery Pakistan) were used. Mixes were analyzed for Air Voids (Va), Voids in Mineral Aggregates (VMA) and Voids Filled with Asphalt (VFA) & designed at optimum asphalt contents, 4 to 6 % Va, and 13% VMA (minimum). Stiffness index (S), an empirical relationship and is the ratio of stability to flow of mixes at 60°C were also determined to add mixes stiffness factor into the model.

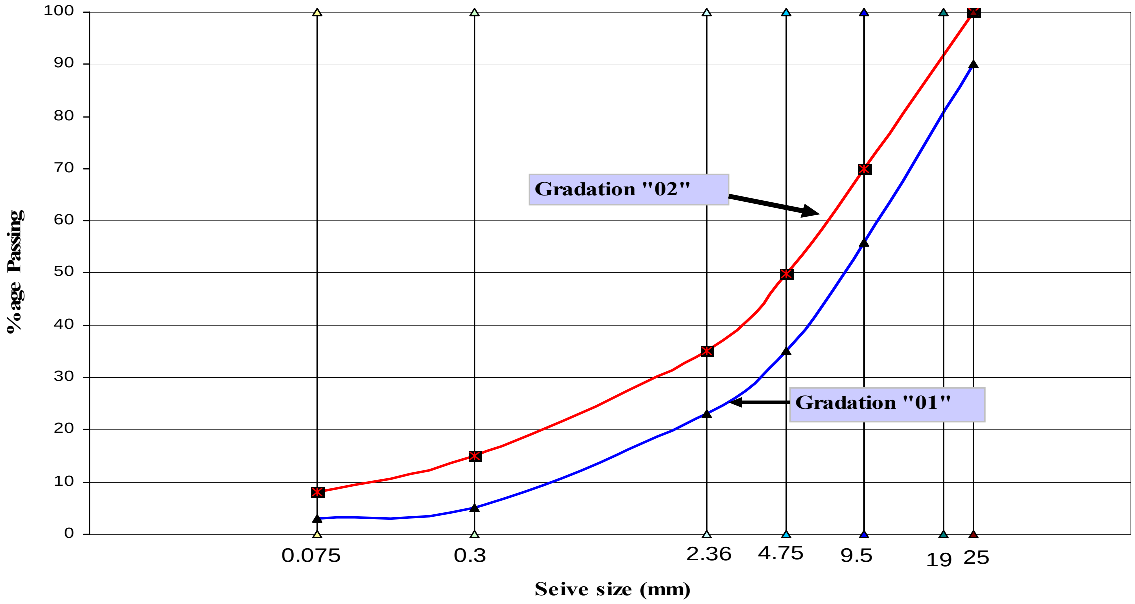

Figure 1: Coarser and finer aggregate gradation

## 4 UNIAXIAL REPEATED CREEP TEST

Specimens (10.2cm x 6.3cm size) were subjected to repeated pulse loading of 1800 cycles under repeated creep test at three test temperatures (25°C, 40°C, & 55°C) and stress levels (100 kPa, 300 kPa, & 500kPa) at Universal Testing Machine (UTM-5P). The temperature and stress taken in this study are representative to the local environmental and load conditions in Pakistan. To depict field trafficking conditions in the laboratory, the specimens were tested by applying square (block) wave load pulses of 500 milli-seconds width and 2000 milli-seconds pulse period.

Resilient modulus, resilient strain and accumulated plastic strain (permanent strain) were measured using two off sample Linear Variable Differential Transformers (LVDTs). Two hours conditioning of specimens in temperature control chamber were carried out before commencement of each test. Permanent strain ($\varepsilon_p$) and resilient modulus (Mr) and of asphalt mixes have been reported in Table 1 &2 respectively.

Table 1: Permanent strain for each sort variable

| Sr. No. | Temperature (°C) | Stress (kPa) | Permanent Strain ($\varepsilon_p$) 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 2: Resilient modulus for each sort variable

| Sr. No. | Temperature (°C) | Stress (kPa) | $M_r$ values of Mixes (MPa) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 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 | 1138 | 1048 | 1130 | 1472 | 1076 | 1490 |
| 2 | 25 | 300 | 486 | 410 | 464 | 722 | 374 | 684 |
| 3 | 25 | 500 | 207 | 158 | 180 | 287 | 144 | 233 |
| 4 | 40 | 100 | 2628 | 2254 | 2606 | 2034 | 2020 | 2437 |
| 5 | 40 | 300 | 1320 | 902 | 1192 | 1114 | 784 | 1002 |
| 6 | 40 | 500 | 538 | 367 | 481 | 450 | 256 | 356 |
| 7 | 55 | 100 | 2808 | 2642 | 2729 | 2311 | 2101 | 2452 |
| 8 | 55 | 300 | 1552 | 1194 | 1416 | 1274 | 862 | 1134 |
| 9 | 55 | 500 | 581 | 445 | 527 | 475 | 292 | 411 |

The influence of stress level on resilient modulus & permanent strain at tested temperature on '$\varepsilon_p$ & $M_r$' has been shown graphically in Figure 2 & 3 respectively. Resilient strain is commonly known as the recoverable strain phase after a loading event that depends mainly on mixe properties, test temperature and loading condition. Resilient modulus is the load induced stress over the measured resilient strain and is an indicator of resistance of mixes to permanent deformations. Figure 2 shows that $M_r$ increases with the increase in stress levels and decreases with increase in temperature.

It can be observed from figure 3 that accumulative/permanent strain ($\varepsilon_p$) for all mixes increases from low temperature (25°C) to high temperature (55°C) i.e change from elastic phase to viscous phase. Figure 2&3 shows that elastic (resilient modulus) and plastic (accumulative strain) properties are highly dependent on the mixture's type, temperature and stress conditions. Moderate effects have however been observed with the change in the gradation.

## 5 DEVELOPMENT OF REGRESSION MODEL

An optimization process using Microsoft Excel Solver (MES) iteration tool was carried out on the data collected. MES performs least-square regression analysis and computes minimum error between the measured permanent strain and the predicted permanent strain. The error can simply be calculated by taking the difference between the predicted and the measured permanent strain in absolute form. The analysis of data initiated with sorting individual effects of stress, temperature, resilient modulus and mix types on the plastic properties. Non liner regression coefficients ($a_1$, $a_2$, $a_3$, $a_4$) were then obtained at least-square of difference between the predicted and measured '$\varepsilon_p$' and at the same time yielding highest coefficient of determination ($R^2$). The relationship between the predicted and the measured permanent strain has been shown in Figure 4.

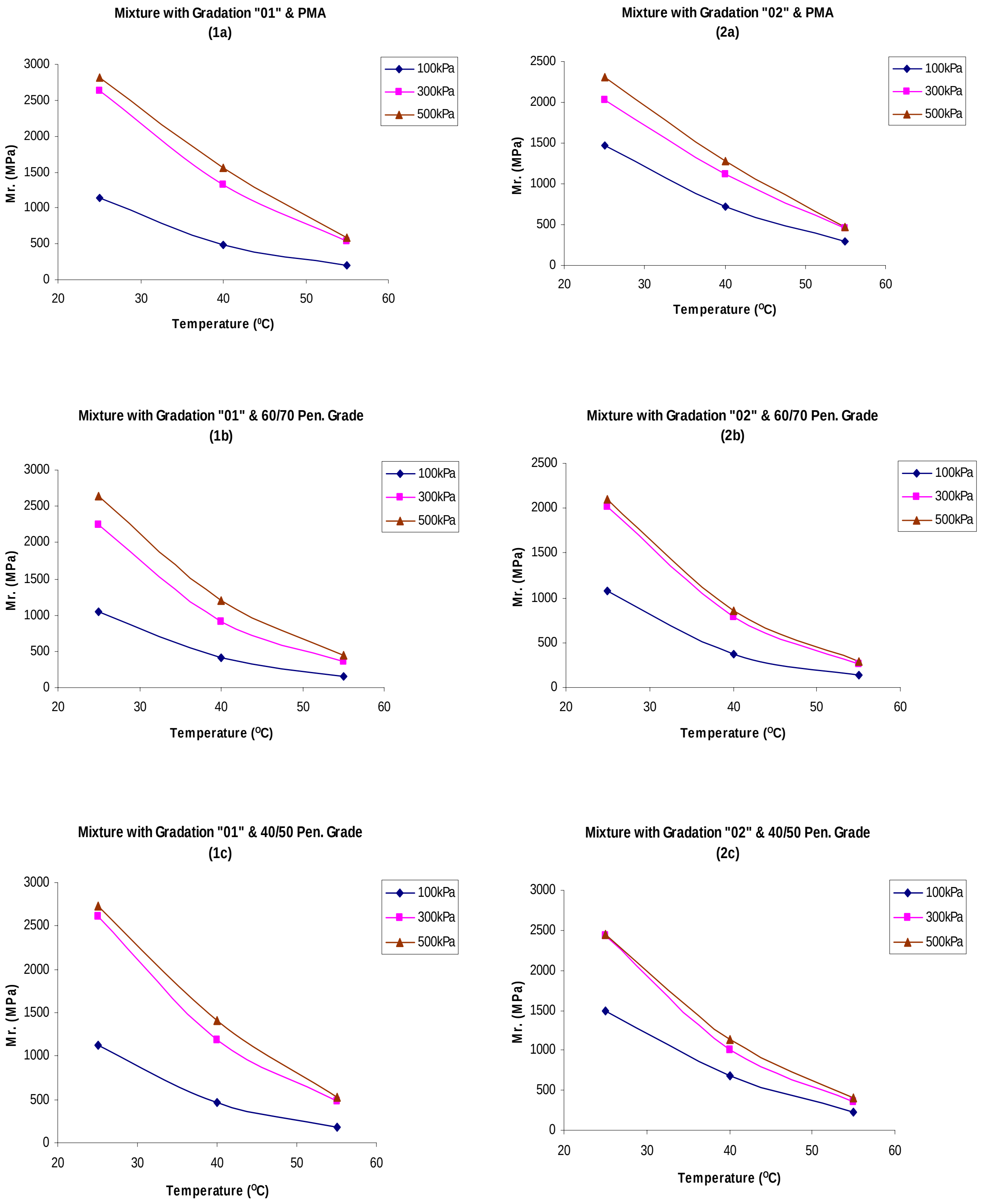

Figure 2: General trends of resilient modulus

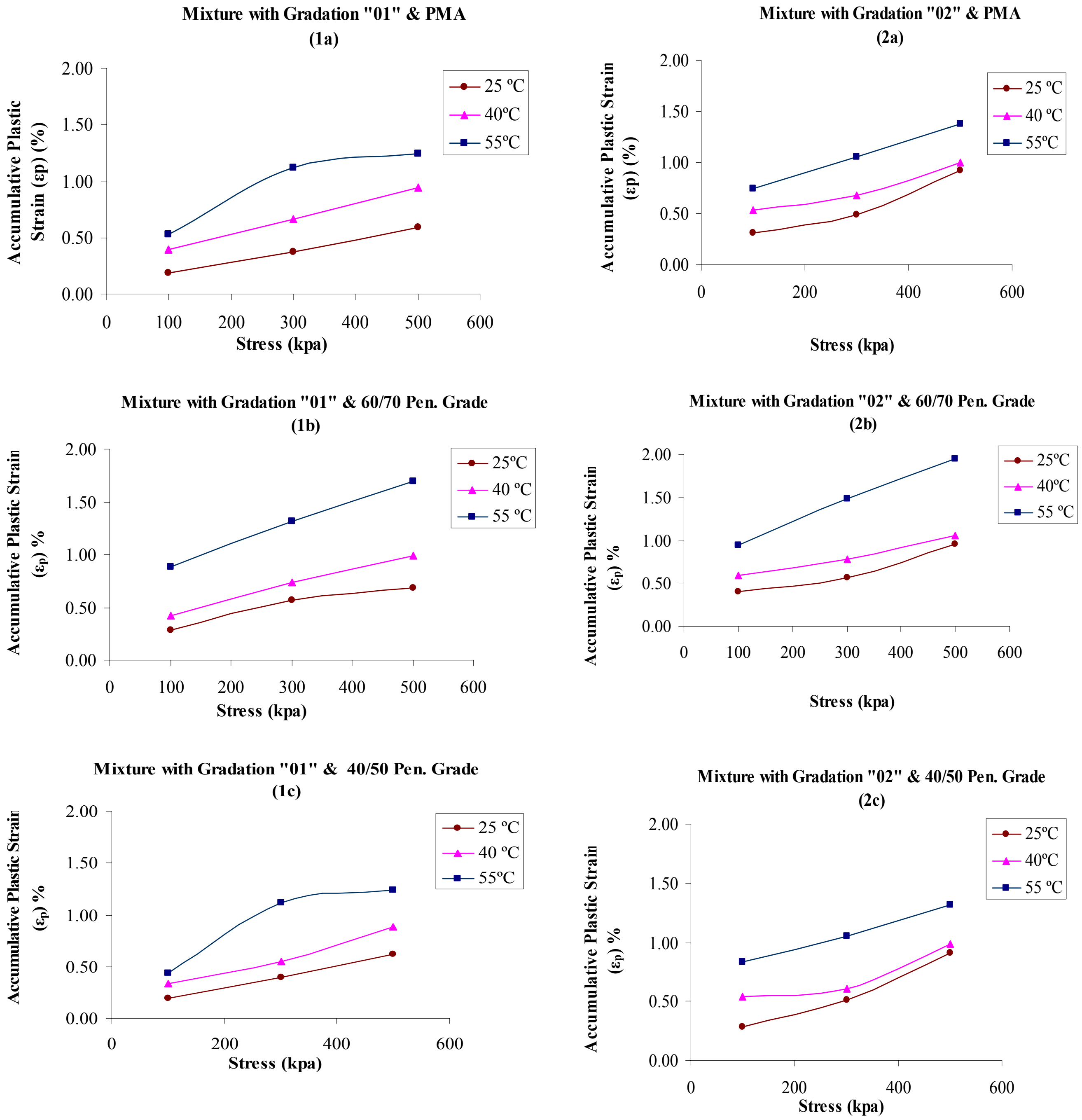

Figure 3: General trends of permanent/accumulative strain

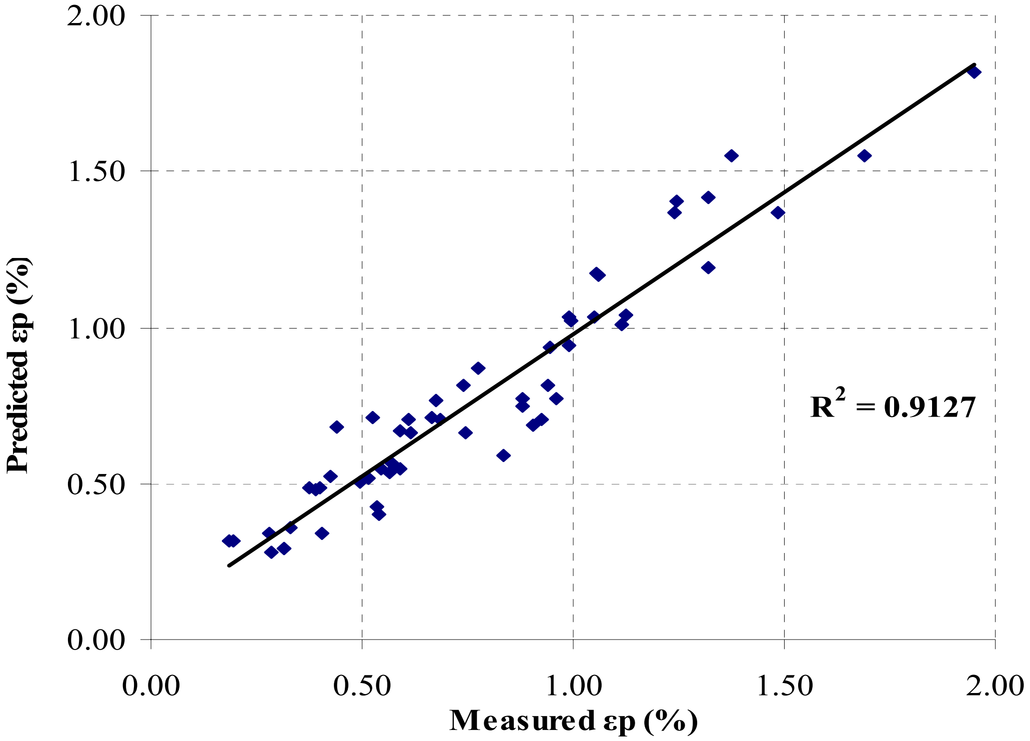

Figure 4: Measured versus predicted εp, $10^6$ in/in

The plot in Figure 4 shows an excellent agreement ($R^2 = 0.913$) between the predicted and measured values of permanent strain. The mathematical form of the model can be presented as follows;

$$\varepsilon_p = \frac{\sigma^{a_1} T^{a_2}}{M_r^{a_3} S^{a_4}} \tag{2}$$

Where:

$\varepsilon_p$ = Permanent Strain

$\sigma$ = Stress (kPa),

T = Temperature (°C)

$M_r$ = Resilient Modulus (kPa)

S = Stiffness Index of Asphalt Cement and,

$a_1$, $a_2$, $a_3$, $a_4$ = Non Linear Regression Coefficient (0.646, 0.25, 0.331, & 0.538 respectively).

The above model can be used to determine the permanent deformation of mixes under repeated loading in terms of resilient modulus. Furthermore, one can predict plastic response of mixes from the elastic response at any stage under the repeated loading. The above equation can be presented in logarithm form after putting regression coefficients, as follows;

$$\log(\varepsilon_p) = 0.646 \log\sigma + 0.254 \log T + 0.331 \log Mr - 0.5381 \log S \tag{3}$$

It can be concluded from the above relationship that permanent strain is a function of stress, temperature, resilient modulus and stiffness index of asphalt mixes.

## 6 CONCLUSIONS

The main objective of the srudy was to develop a regression model to assess the plastic/permanent strain from the elastic component (resilient modulus) of asphalt cement concrete. The following conclusions have been drawn;

- Permanent strain can reasonably be depicted from the resilient property of the asphalt mixtures for the proposed mathematical model.
- Permanent strain is a function of stress level, temperature, resilient modulus and stiffness index of the asphalt concrete.
- Stress level and stiffness index (mix property) has a significant effect on permanent strain.

## REFERENCES

American Society for Testing and Materials (ASTM). 2004. “*Test Method for Indirect Tension Test for Resilient Modulus of Bituminous Mixtures*”. ASTM Designation D4123

Anderson R.M., Turner P.A., Peterson R.L. and Mallick R.B., “*Relationship of Superpave Gyratory Compaction Properties to HMA Rutting Behaviour*”, National Cooperative Highway Research Program, NCHRP Report 478, Transportation Research Board, Washington, D.C., 2003.

Faheem A. F., Bahia H. U. and Ajideh H., “*Estimating Results of a Proposed Simple Performance Test for Hot-Mix Asphalt from Superpave Gyratory compactor Results*”, Transportation Research Board Annual Meeting, Washington, D.C., 2005

Fujie Z., Tom Scullion and Lijun Sun, 2004. “*Verification and Modeling of Three-Stage Permanent Deformation Behavior of Asphalt Mixes*”, Journal of Transportation Engineering, Vol. 130, No. 4, July/August, pp. 486-494.

Hassan Ziari, Mahmud Ameri، and Mohammad Mahdi Khabiri; 2007. “*Resilient Behavior of Hot Mixed and Crack Sealed Asphalt Concrete under Repeated Loading*” Iran Science and Technology University, ISSN 1392-8619 print/ISSN 1822-3613 online, Vol XIII, pp 56-60.

Kamal M.A., Shahzeb F., Baber Y., 2005. “*Resilient Behavior of Asphalt Concrete under repeated loading & effects of temperature*” Journal of the Eastern Asia Society for Transportation Studies, Vol. 6, pp 1329-1343.

National Cooperative Highway Research Program, “*Guide for Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures”*, NCHRP, Part 3– Design Analysis, Chapter 3 Design of New and Reconstructed Flexible Pavements”, 2004.

National Highway Authority, NHA., 1998, “*General Specifications*”, Surface Courses, Item No. 305, Pakistan

Paterson, W.D.O., 1987. “*Road Deterioration and Maintenance Effects*”: "Models for Planning and Management, World Bank, Washington, D.C.

Shah A., McDaniel R. and Gallivan V., “*Evaluation of Mixtures Using Dynamic Modulus Tester: Results and Practical Considerations*”, Journal of the Association of Asphalt Paving Technologists, Volume 73, 2004.

Su K., Li-J.S., and Yoshitaka H., (2008). “*A New Model for Predicting Rutting in Asphalt Pavement Employing Static Unaxial Penetration Test*”, International Journal of Pavement Research Technology, Chinese Society of Pavement Engineering, ISSN 1997-1400, Vol. 1, No.1, pp 24-33.

Stephen P., Yusu M., and Leslie M. McCarthy. (2007). “ *Evaluation and Modeling of Repeated Load Test Data of Asphalt Concrete for Mechanistic-Empirical Pavement Design*”, Journal of Materials in Civil Engineering, ASCE, pp 993-999, Vol. 19, No. 11, November 2007.