RESTRICTED ZONE OF SUPERPAVE MIX DESIGN AND ITS IMPACT ON RESILIENT MODULUS AND PERMANENT DEFORMATION

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ABSTRACT

Back in 1993, Strategic Highway Research Program introduced new mix design method known as SUPERPAVE that is an acronym of Superior Performing Asphalt Pavement. Superpave caters filed performance of bituminous mixes and Superpave gradation chart includes 0.45 power line, restricted zone and control points. In Superpave, the gradation that compliance with the restricted zone was considered less rut resistant as compared to gradation passing outside the restricted zone. This study targets three types of gradations that passed above, below and through the restricted zone. The results show that the gradation passing through the restricted zone not only satisfy Superpave volumetric requirements but also performs better against rutting as compared to gradation passing outside the restricted zone. Resilient modulus (M_R) measured through indirect tensile strength setup that defines the elastic properties of bituminous mix under repeated load test. Laboratory study was conducted to find factors that affect the gradation. Two-way factorial design was carried out by using Minitab-15 statistical software and the results reflected that the individual factor i.e. loads duration and temperature as well as interaction of factors has significant effect on the performance of HMA.

KEYWORDS

Resilient Modulus; Permanent Deformation; Hot Mix Asphalt (HMA); Restricted Zone; Superpave

INTRODUCTION

Asphalt concrete is composed of binder and aggregate. In asphalt pavement 94% to 95% is aggregate whereas remaining portion is binder that acts as gluing agent. In hot mix asphalt the aggregate provides strong aggregate skeleton to resist each application of load. When load is applied the rough and angular aggregates tightly lock with each other and offer a single elastic mass with larger size thus enhancing the shear strength of asphalt mixtures. Therefore, gradation is an influential characteristic of aggregate that affects the performance of HMA like fatigue cracking and permanent deformation. Mixes having different gradation have different stability and rutting potential. To encounter permanent deformation issues SHRP introduced new mix design method named as SUPERPAVE and specifications for aggregate gradation chart. The gradation chart has maximum density line, control points and restricted

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zone. Maximum density line splits coarse gradation with finer one, control point serves as master range through which gradation must pass whereas the restricted zone restricts the gradation to pass through the restricted zone. In this study three gradations passing Above the Restricted Zone (ARZ), Below the Restricted Zone (BRZ) and Through the Restricted Zone (TRZ) are considered.

Resilient modulus test is carried out on laboratory fabricated specimen by employing repeated load indirect tension test according to ASTM standard D4123. The test is performed on cylindrical specimen that is subjected to compressive loads and the results are shown in haversine or triangular waveform. The recoverable horizontal deformation of each cylindrical specimen is measured with assumed poisson's ratio and resilient modulus is calculated. Resilient modulus M_R is defined as ratio of applied deviator stress to recoverable strain as shown in below Equation 1.

$$M_R = \frac{\sigma_d}{\varepsilon_r} \tag{1}$$

where, σ_d is defined as deviator stress i.e. vertical or axial stress whereas ε_r is defined as recoverable strain. Small portion of deformation may be recoverable or resilient whereas remainder will be plastic or unrecoverable. Large amount of plastic strains are present at initial stage of test whereas plastic stain starts to diminish as load increases under the action of repeated load test. It is said that after 100 to 200 load cycles of repetition, the strain is mostly recoverable [1].

Three gradation band (upper gradation band, lower gradation band and middle gradation band) of one NMAS (19mm) was selected to find the rutting potential of the HMA mixtures. It can be determined that the gradation of aggregate plays significant role in rutting propensity and this fact proves that structure of aggregate is the main load carrying factor of bituminous mixes. The skeleton provided by middle gradation in mixture has the lowest deformation and its resilient modulus value is the highest whereas the skeleton provided by mixture with lower gradation showed highest deformation and the lowest resilient modulus value [2].

Two wearing and one base asphalt concrete mixtures were taken (ACW14, ACW20 and ACB28), resilient modulus was analysed by varying bitumen content by interval of 0.5% and at two different temperatures. With the increasing bitumen content and temperature, resilient modulus decreased because strength of the mixture reduces with the increase in bitumen content. On the other hand higher grading (ACB 28) give higher resilient modulus [3].

Effect of resilient modulus on specimen thickness, diameter and aggregate NMAS and three loading factor including load, waveform and strain level was computed. It was believed that resilient modulus decreases as load duration increases because plastic strain becomes higher [4].

Indirect tensile strength, dynamic modulus, uniaxial creep and flexural fatigue test are carried out for surface mix 9.5mm and base mix 25.0 mm and results were analysed at different temperatures. The results derived show that increase in temperature decreases the resilient modulus and IDT strength of 9.5mm surface are higher than 25.0mm base mix [5].

Another literature review of thirteen published papers to study the SUPERPAVE restricted zone and its impact on the performance of aggregate gradation was carried out. The literature review included extensive range of aggregates, gradations, NMAS, and performance testing. The results obtained by reviewing the papers are that the gradations passing TRZ

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perform better as compared to gradation passing outside the restricted zone. It is indicated clearly by the reviewed research that mixtures with fine graded gradations which either passes above the restricted zone or that passes through the restricted zone perform the best and thus these gradations perform better than mixtures with gradations that passes below the restricted zone. The recommendations obtained suggested that the concept of restricted zone should be eliminated from the specifications of Superpave because several research pointed that satisfactory results could be achieved with gradations ranging from BRZ to ARZ and no interaction were seen between the fatigue and rutting performance of hot mix asphalt and the restricted zone of Superpave mix design [6].

Hot mix asphalt designed by superpave mix design procedure with gradation passes ARZ typically showed least amount of rutting unlikely for mixtures with gradation passes BRZ which typically showed high level of rutting [7].

For limestone and granite, asphalt wearing course mix with gradation passing below the restricted zone typically showed the lowest rut resistance, mixes with gradation passing through the restricted zone typically showed the highest rut resistance, and mixes with gradation passing above the restricted zone typically showed an intermediate rut resistance. While for gravel mixtures with gradations passing below the restricted zone typically showed the highest rut resistance, gradation passing above the restricted zone typically showed the lowest rut resistance, and mixtures with gradation passing through the restricted zone typically showed an intermediate rut resistance. [8].

It is confirmed that in the theory of SHRP – Superpave the volumetric and composition correlate up to some extent i.e. mixes with gradation passing TRZ may have higher value of voids filled with asphalt and lower value of void in mineral aggregate. Mixes containing gradation passes TRZ cannot be characterized with worst mechanical properties [9].

Mixes having gradations passes TRZ will give results somewhat comparable or even better than the mixes with gradations that pass either ARZ or BRZ. This result was concluded from the experiments conducted on mixes with gradations having maximum aggregate size of 12.5 mm, 19 mm and 25 mm applying gyrations of 50, 70 and 100 at N design value. Also the mixtures having aggregate gradations passes BRZ appears to be more affected by aggregate properties than that of the mixes with gradations passes either TRZ or ARZ [10].

The asphalt mixtures with gradations passes TRZ, Hump through the restricted zone and Crossover through the restricted zone with the three Nominal Maximum Aggregate Size of (9.5, 12.5, and 19.0 mm) were resulted with higher value of air voids than the asphalt mixes with aggregate gradation passes ARZ and BRZ, and hence could be more susceptible to rutting [11].

RESEARCH METHODOLOGY

Aggregates were procured from Margalla quarry site whereas the 60/70 grade binder was procured from Attock Oil Refinery. Sieve analysis was done and aggregates were stored in respective bins. Aggregates were then procured from respective bins to achieve the required gradation blend. Optimum bitumen was calculated for each gradation blend (ARZ, TRZ and BRZ) by compacting the specimen in Superpave gyratory compactor (SGC). The resilient modulus of each gradation was carried by UTM-25 at two different temperatures (25 ℃ and 40 ℃) according to ASTM standard D4123 and conclusions were drawn for the ARZ, TRZ and BRZ.

Mixtures Description

Superpave gradation consists of 0.45 power line enveloped by control points and restricted zone. Control points define the maximum and nominal maximum aggregate size as well as the dust proportion. On the other hand restricted zone restricts the gradation that passed TRZ because it was believed that the gradation passes TRZ will produce the tender mix. This study is based on three Superpave gradations that are named as ARZ, BRZ and TRZ. Figure 1 shows the 19.0mm NMAS Superpave gradation blend (ARZ, TRZ and BRZ).
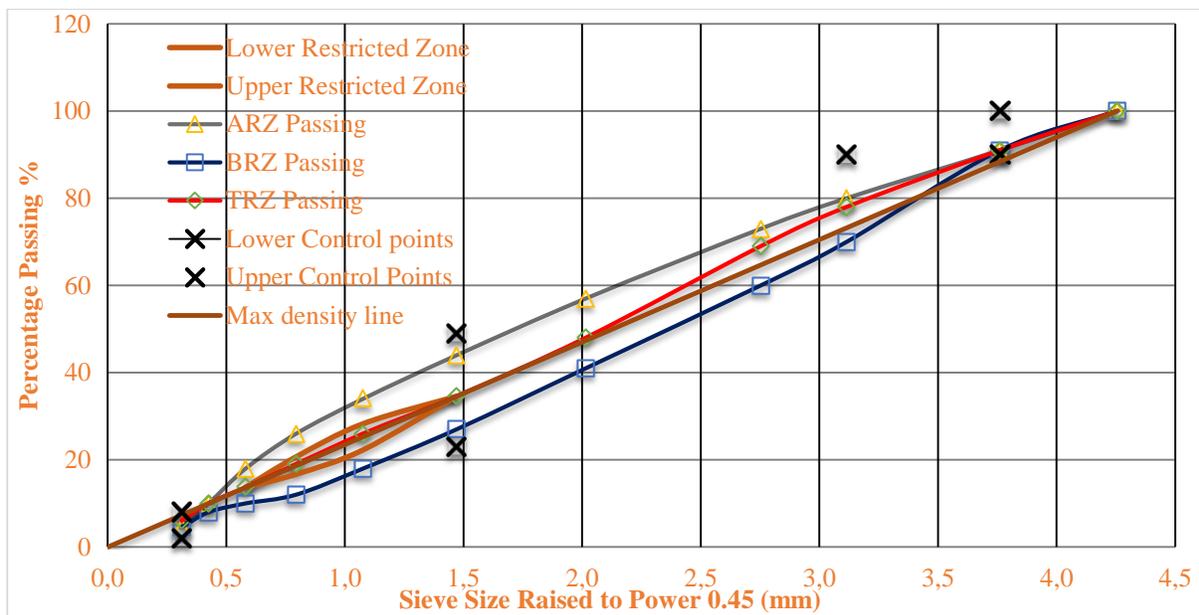
Fig. 1 – Gradation Chart with 19.0mm NMAS

Asphalt Mixtures Preparation

Three gradations (ARZ, TRZ and BRZ) of 19.0mm NMAS were prepared in laboratory by using Superpave design method. The specimens were compacted by employing SGC that compacts each gradation at 125 numbers of gyrations. The optimum bitumen content and volumetric was determined for each gradation as shown in below Table 1.

Tab.1 - Volumetric of Superpave Gradations

Gradation	% VMA	%G_{mm} @ N_{ini}	Design P_b %	Design P_{be} %	P_{200}/P_{be}
TRZ	13.21	85.60	4.00	3.97	1.13
BRZ	13.48	84.20	4.20	4.10	1.46
ARZ	13.40	87.90	4.30	3.82	1.17

-VMA= Voids in Minerals Aggregate
- G_{mm} = maximum specific gravity of paving mixture (no air voids)
- P_b = Asphalt, percent by total weight of mixture
-P_{be}= Percent Effective Bitumen
-P_{200} = Aggregate content passing the 0.075-mm sieve, the percent by mass of aggregate.

All the specimens were processed through core cutting for the diameter of 100 mm. Saw cutting was performed to cut samples with height of 50 mm and 100 mm in diameter. Figure 2 shows sample for IDT and Resilient Modulus Tests whereas Figure 3 shows the specimen for wheel tracker test.

Fig. 2 – Specimens for IDT and MR Tests

Fig. 3 - Specimens for HWT Test

Input Parameters

Following Input parameters were selected as shown in Table 2 and fed into the testing software and specimens were subjected to Resilient Modulus test as per ASTM D4123:

Tab.2 - Input parameters

Parameters	Selected Values
Peak Loading Force	20% of IDT strength
Searing Force	10% of Peak Loading Force
Poisson's Ratio (assumed)	0.4
Conditioning Pulses	100
M_R Data Collection Pulses	5
Temperature	25 and 40 Degree C
Loading Duration	100 and 300 ms

RESULTS AND DISCUSSIONS

The tests were conducted on the prepared samples using the input parameters as defined. Since tests were performed on two temperatures and two loading durations, plots were plotted for ARZ, TRZ and BRZ as shown in below Figure 4 and 5.
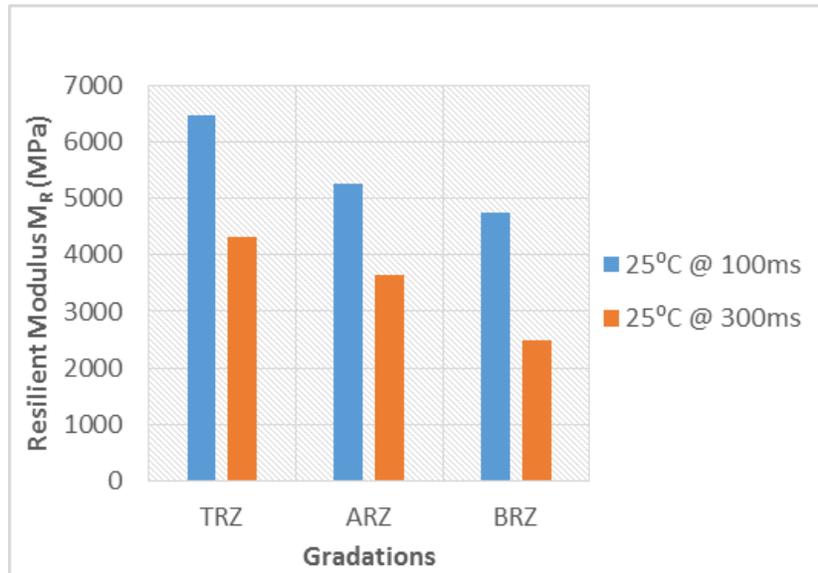
Fig. 4 – Resilient Modulus of Gradation at 25 °C
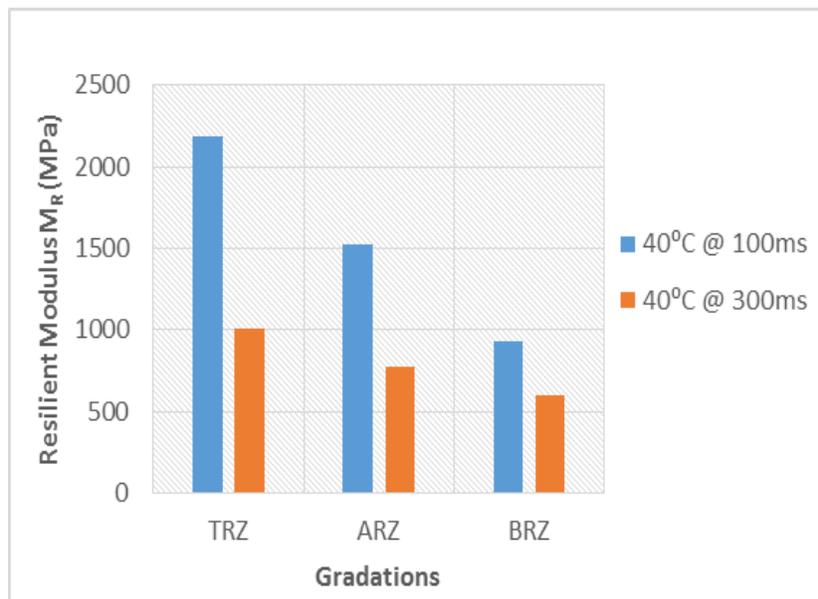
Fig. 5 – Resilient Modulus of Gradation at 40 °C

Figure 6 shows the effect of gradation on rutting. Gradation passing BRZ has marginally higher rut depth as compared to gradation passing ARZ and TRZ. Gradation passing TRZ that was considered as rut prone performs best as compare to rest of gradations.
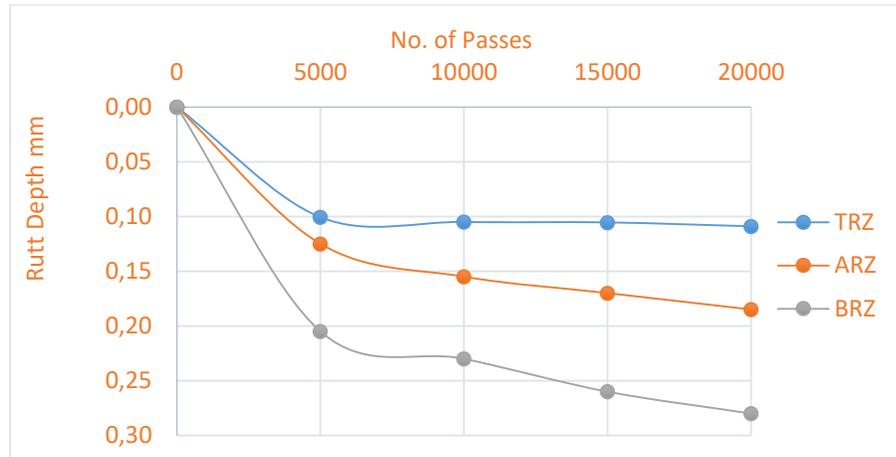
Fig. 6 - Gradation effect on Rut Depth

Analysis of rut depth was evaluated by conducting one way ANOVA. Table 3 shows the ANOVA conducted on HWT test results. Which clarify that the gradation has significant effect on rutting propensity.

Tab. 3 - Analysis of Variance of Rut Depth

Source	DF	SS	MS	F	P
Gradation	2	0.029108	0.014554	205.47	0.001
Error	3	0.000212	0.000071		
Total	5	0.029321			

Analysis of Resilient Modulus Test Results

In this research, two factors were considered and are presented in Table 4 with their respective abbreviations including high and low levels. Design of experiments was carried out using Minitab-15 statistical software separately for ARZ, TRZ and BRZ.

Tab. 4 - Factors for ARZ, TRZ and BRZ

Acronyms	Factors	Levels	Units
A	Temperature	100 and 300	ms
B	Load Duration	25 and 40	ºC

In Analysis of Variance ANOVA, three F-tests are made and level of significance (α) was chosen to be 0.05. To evaluate these five tests, the probability results are given as shown in Table 5, 6 and 7.

Tab.4 - Analysis of Variance for ARZ

Source	DF	Sequential Sum of Squares	Adjusted Sum of Squares	Adjusted Mean Squares	F-Test	P-Test	Significance at 95%
Main Effects	2	36696327	36696327	18348163	880.47	0.000	Yes
2-Way Interactions	1	563767	563767	563767	27.05	0.001	Yes
Residual Error	8	166713	166713	20839			
Pure Error	8	166713	166713	20839			
Total	11	37426807					

Tab.5 - Analysis of Variance for TRZ

Source	DF	Sequential Sum of Squares	Adjusted Sum of Squares	Adjusted Mean Squares	F-Test	P-Test	Significance at 95%
Main Effects	2	51458190	51458190	25729095	1189.71	0.000	Yes
2-Way Interactions	1	672133	672133	672133	31.08	0.001	Yes
Residual Error	8	173011	173011	21626			
Pure Error	8	173011	173011	21626			
Total	19	52303334					

Tab.6 - Analysis of Variance for BRZ

Source	DF	Sequential Sum of Squares	Adjusted Sum of Squares	Adjusted Mean Squares	F-Test	P-Test	Significance at 95%
Main Effects	2	29551222	29551222	14775611	14831.23	0.000	Yes
2-Way Interactions	1	2818821	2818821	2818821	2829.43	0.000	Yes
Residual Error	8	7970	7970	996			
Pure Error	8	7970	7970	996			
Total	11	32378013					

Interactions

The hypothesis that is carried out by Minitab-15 software has its inherently capability to carry out interaction as explained below:

Null Hypothesis: Ho = Interactions are Insignificant

Alternative Hypothesis: Ha = Interactions are Significant

According to results displayed in tables above, the 2-way interactions have P-test value less than level of significance (LOS; $\alpha=0.05$), so we concluded that reject the null hypothesis in the favour of alternative hypothesis. So, two way interactions are statistically significant.

Significant Effects and Interaction Plots

The factors and interactions of factors affecting the resilient modulus of asphalt concrete specimen are shown in Pereto Chart of Standardized effect by using Minitab-15 Statistical Software. Pareto plot shows the absolute values of effect whereas reference line drawn shows t-distribution. The result drawn from the plot shows that individual factors and interactions of the factors are significant for all the three gradation shown in Figure 5, 6 and 7.
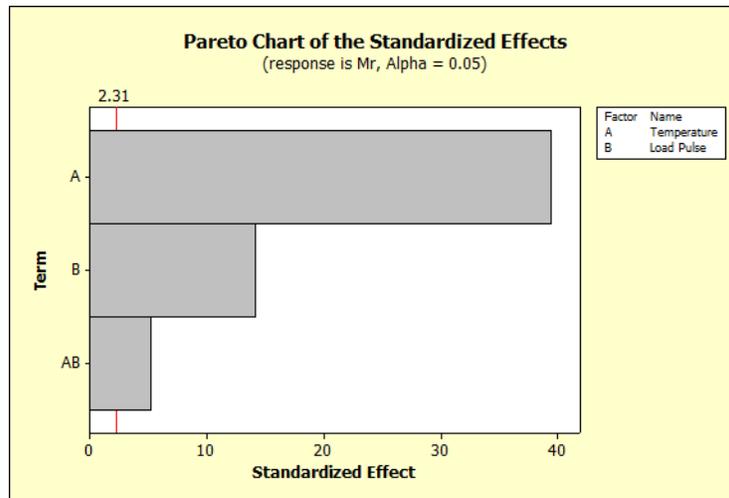
Fig. 5 – Pareto Chart for TRZ
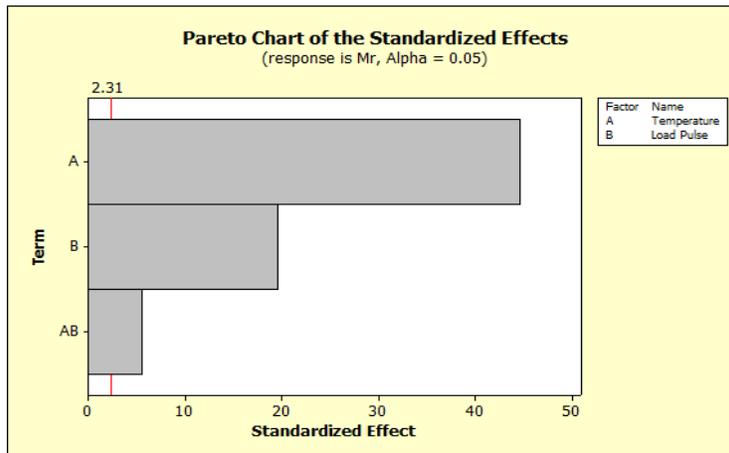
Fig. 6 – Pareto Chart for ARZ
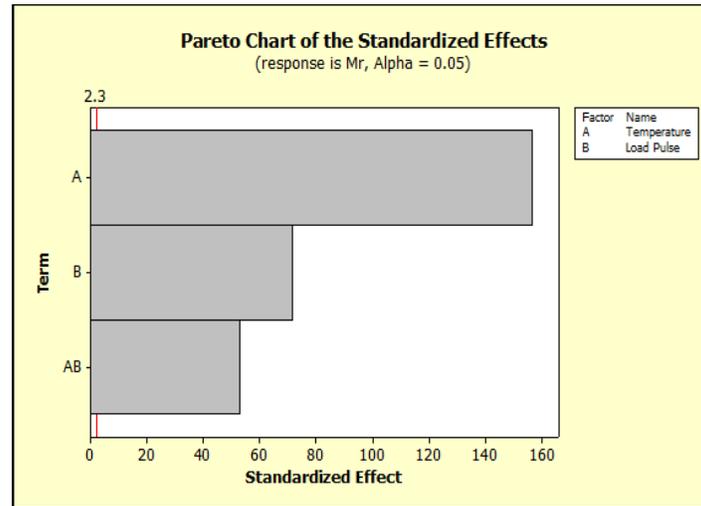
Fig. 7 – Pareto Chart for BRZ

Factorial Plots

The significant effect and the interaction obtained through Pareto will be discussed with the help of factorial plots. The individual factors are shown with main effect plots whereas two way interactions are explained through interaction matrix.

Main Effect Plots:

Main effect plots of ARZ, TRZ and BRZ are shown in Figure 8 below.
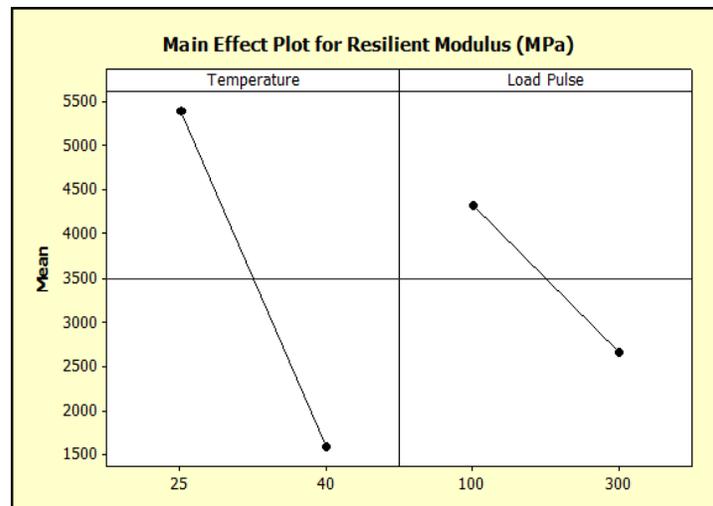
Fig. 8 – Main Effect plot for ARZ, TRZ and BRZ

The conclusion derived from the temperatures plot is that the M_r value of the asphalt concrete specimen is decreased with the increase of the temperatures from 25 ºC to 40 ºC. The decrease in resilient modulus is due to softening of asphalt concrete that in return reduces the stiffness of the specimen and increasing the recoverable strains and results in the reduction of M_r.

The inference drawn from the load duration plot shows that longer load duration lowers the resilient modulus for ARZ, TRZ and BRZ. This was obvious because due to longer load duration asphaltic concrete specimen experiences higher strain for long period of time and in return reduces the M_r. Reduction in resilient modulus at longer load duration can be explained by the viscoelastic nature of asphalt concrete. It can be concluded that slow moving traffic has more adverse effect on pavement surface resulting in permanent deformation of pavement.

Interaction Plots

Figure 9 presents the interaction plot of different factors (load durations and temperatures) on ARZ, TRZ and BRZ.
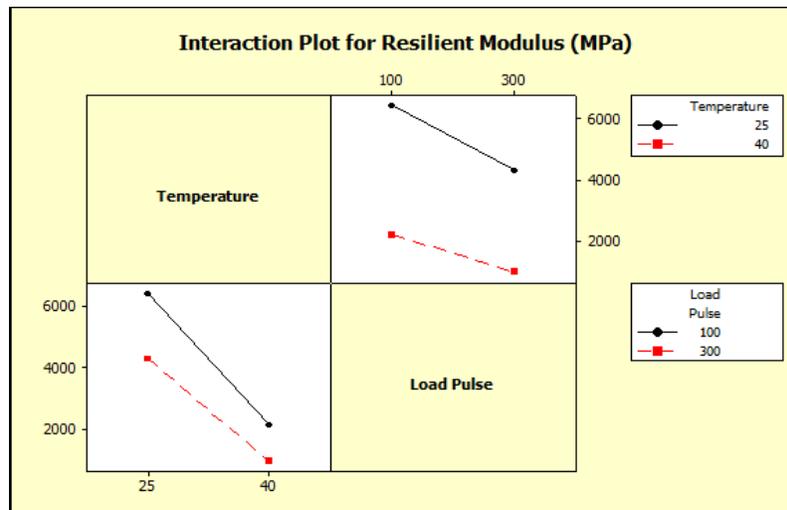
Fig. 9 – Interaction plot for ARZ, TRZ and BRZ

The conclusions derived from the interactions plots of ARZ, TRZ and BRZ are described below.

The interaction of Temperature and Load pulse vs. resilient modulus of the mixtures shows that at low temperature and smaller loading duration resilient modulus is higher whereas at high temperature and longer duration resilient modulus decreases. This is due to the reason when load is applied for smaller duration (due to slow moving traffic or static loaded traffic) at low temperature, asphaltic concrete mixture behave stiffer and the pavement surface is less prone to rutting. This HMA specimen is having high resilient modulus. But when a load is applied for longer duration and at high temperatures the scenario is totally different. The asphaltic concrete specimen becomes less stiff at higher temperature and results in lower resilient modulus.

SUMMARY AND CONCLUSION

Factorial Design was conducted to find the effect of the variable that influences the resilient modulus. The important aspect of factorial design was testing the existence of interaction among the factors. Loading Duration and temperature effect was found to be the most effectual factor on resilient modulus of asphaltic concrete. Loading pulse has significant effect on ARZ, TRZ and BRZ. Increasing the loading duration from 100 ms to 300 ms results in decrease of resilient modulus on average for ARZ, TRZ and BRZ. The decrease in resilient modulus is due to the fact that specimens experienced strains for longer period of time. Temperature has pronounced effect on ARZ, TRZ and BRZ. Increasing temperature from 25 ºC to 40 ºC decrease the resilient modulus significantly. The drop down in resilient modulus emphasized on the fact that asphalt concrete is temperature dependent. At higher temperature asphalt becomes viscous and aggregates contribution becomes more significant. Two ways interaction results obtained through statistical analysis depicts that resilient modulus of ARZ, TRZ and BRZ are sensitive to load pulse and temperature interactions. It can be easily stated from the performance testing results that TRZ that was considered as rut prone performs better as compared to gradation that are passing ARZ and BRZ and ANOVA conducted on HWT test results clarify that the gradation has significant effect on rutting propensity.

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