Performance Evaluation of Asphaltic Mixtures Using Bakelite

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Abstract: This research evaluates the performance of various hot mix asphalt mixtures. Four HMA mixtures (two controlled and two modified) for wearing course were evaluated within envelope of national highway authority (NHA's) class A and class B gradations using Superpave mix design method. Bakelite, an old plastic was added as modifier to the penetration grade 60/70 binder. This study investigated the rutting resistance by Hamburg Wheel tracker test at room temperature and stiffness by dynamic modulus test at various temperatures (25, 40 and 50˚C) and frequencies (0.1, 0.5, 1, 5, 10 and 25 Hz) using Asphalt Mixture Performance Tester (AMPT). The test results indicated that with the addition of bakelite, the performance of mixtures improved significantly. The percentage reduction in rut depth at 6% optimum bakelite content was found to be 29% and 38% for class A mixtures and class B mixtures, respectively when compared to controlled mixtures. Likewise, the percentage increase in dynamic modulus values was found to be 36% and 46% for class A mixtures and for class B mixtures at 50°C respectively. The statistical technique of Full Factorial Design of Experiments was used and results revealed that frequency was found to be the most effectual factor on the dynamic modulus, followed by temperature and bakelite. This research would facilitate the pavement engineers to minimize the distresses during the service life using bakelite as a modifier.

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1. Introduction

Asphalt pavements mainly consists of two basics components that are aggregate and asphalt binder. These two components (aggregate and asphalt) in HMA mixtures are optimally mixed in quantity to produce an economical mix design. Pavements in torrid zones of Pakistan are facing grave problem of developing ruts. This is mainly due to the drastic increase in road traffic during the last two decades. Material characterization is an important phase for performance and design of flexible as well as rigid pavements. The design life of a pavement mainly revolves around the mix design as it governs the performance of pavements.

Rutting, also called as permanent deformation or creep in 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. It is a phenomenon that is developed in all layers of flexible pavements, under the application of repeated traffic loading, by the accumulation of permanent strains [Asphalt institute SP-2]. It has been reported that rutting increases with increase in temperature even under well controlled loading conditions and asphalt mixes built up more resistance to flow during the process of deforming under repeated loading (Hofstra et.al 1972). "The complex modulus is defined as the complex number that relates stress and strain for a linear viscoelastic material subjected to sinusoidal loading, the absolute value of complex modulus is commonly called as dynamic modulus". The two properties determined from complex modulus testing are dynamic modulus (E*), and phase angle (Ø). The dynamic modulus is the main input parameter for mechanistic empirical pavement design guide (MEPDG) of hot mix asphalt (HMA) due to which it has gained more attention recently. Dynamic modulus can be determined by temperature and loading rate-dependent actions of Hot mix asphalt in MEPDG. In dynamic modulus test deformation are measured by application of sinusoidal loads. The ratio of stress to the strain amplitude is called as dynamic modulus.

Al-Khateeb et al. (2013) reported that basalt superpave asphalt mixtures showed higher resistance to rutting as compared to the limestone superpave asphalt mixtures. Also the difference in number of loading cycles to rutting failure between limestone and basalt asphalt mixtures was statistically significant at a level of $\alpha = 0.1\%$ for all temperatures. Hafeez et al. (2012) concluded that Wheel tracker rut depth factor and dynamic modulus rutting factor are related to each other and polymer modified asphalt mixtures yielded in low rutting and high dynamic modulus values. Ahmad et al. (2011) developed a correlation between rut stiffness factor from AMPT dynamic modulus test at 5Hz frequency and rut depth from wheel tracker at 40, 45 and 50˚C. Kim et al. (2009) concluded that RAP mixtures with modified binders have shown good resistance to rutting irrespective of the amount of RAP materials in HMA. A study indicated that rutting in multilayer specimens has an indirect relation with temperature and applied loading (Weidong et al. 2006). Khan et al. (2008) concluded that rut depth has a direct relation with no of passes and temperature.

Contreras et al. (2010) concluded that for asphalt mixtures tested ultrasonically the increase in magnitude of dynamic modulus can be associated with an increase in the frequency used but it may be due to different testing method. A study indicated that percentage of slag affect the strength of mix and also developed predictive model for dynamic modulus (Hassan and Al Jabri, 2011). Apeagyei (2011) reported that dynamic modulus and gradation is one of parameter considered for rutting potential. Zhu et al. (2011) investigated the effect of modifier on the performance of asphalt mixes by dynamic modulus test.

This paper aims to evaluate the performance of HMA mixtures using bakelite as modifier, the rutting susceptibility and the factors affecting the dynamic modulus of superpave mixes. By using the test results it is hoped that the approach present in paper could be useful in determining pavement response and the factors affecting it.

2. Objective and Scope

The main objective of this paper is to evaluate the effect of bakelite on performance of HMA mixtures, the rutting susceptibility of HMA mixtures and to determine the factors affecting the dynamic modulus for wearing course mixes. The laboratory results were used as input in statistical software and factorial design of experiment method was carried out for determination of factors affecting dynamic modulus.

The scope of study was constrained to two different wearing course mixes of NMAS 19mm and 12.5 mm under the envelope of NHA class A and Class B gradations. The asphalt binder used is penetration grade 60/70. Bakelite was used as a modifier. Optimum bitumen content was determined for each mix using Superpave mix design technique. Wheel tracker test was conducted on laboratory prepared gyratory specimens at room temperature. Dynamic modulus test was conducted at three different temperatures (25, 40 and 50˚C) and six different frequencies (0.1, 0.5, 1, 5, 10 and 25Hz).

3. Methodology

This paper elaborates the testing of two different mixes and the methodology adopted can be seen by figure 1. Class A and class B mixes under the envelope of NHA gradations for wearing courses were selected. These specifications are most frequently used by highway agencies for wearing courses in Pakistan.

The gradation charts for HMA mixtures are shown in figure 2. These charts include the percent passing of individual sieves raised to power 0.45 along with the upper and lower limits of NHA A and B general specifications. The percent passing of individual sieves were further plotted against the superpave control points for NMAS 19mm and 12.5mm. After selection of gradations, Superpave specimens were prepared to determine the optimum binder content and volumetrics. Optimum bakelite content was determined by varying the quantity of bakelite from 1.5 to 9% by weight of bitumen and keeping the Optimum bitumen content determined for each gradation constant. The volumetric properties of each mix are given in table 1.

After determination of optimum bitumen content, Superpave gyratory compacted specimens were prepared for dynamic modulus test in accordance with AASHTO TP 62-07 and for wheel tracker test in accordance with AASHTO T 324-04. The specimens were sawed and cored carefully as per required dimensions for dynamic modulus test and wheel tracker test. The height and diameter of specimens 38.1 mm and 150 mm respectively for wheel tracker test. The height and diameter of specimens 150 mm and 100 mm respectively for dynamic modulus test.

The studs were fixed using epoxy glue by application of gauge point fixing jig apparatus for dynamic modulus test. These studs enable to measure axial strain by use of linear variable differential transformer (LVDT). After determination of optimum bitumen content, Superpave gyratory compacted specimens were prepared for dynamic modulus test in accordance with AASHTO TP 62-07 and for wheel tracker test in accordance with AASHTO T 324-04. The specimens were sawed and cored carefully as per required dimensions for dynamic modulus test and wheel tracker test. The height and diameter of specimens 38.1 mm and 150 mm respectively for wheel tracker test. The height and diameter of specimens 150 mm and 100 mm respectively for dynamic modulus test. The studs were fixed using epoxy glue by application of gauge point fixing jig apparatus for dynamic modulus test. These studs enable to measure axial strain by use of linear variable differential transformer (LVDT).

Wheel tracker test was performed on Hamburg Wheel tracker device, which is commonly used test for determining rutting in HMA mixes. Wheel tracker is an electrically powered device, which is capable of moving a 203.2mm diameter, 47-mm wide steel wheel over a test specimen. The load on the steel wheel is 158±1.0 lb. and the average contact stress produced by the contact of wheel is approximately 0.73 MPa with a contact area around 970 mm^2. The contact pressure induced by the steel wheel produces the same effect as produced by the rear tire of a double-axle truck. The steel wheel should complete approximately 50 passes over the specimen per minute. Its maximum speed is approximately 1 ft. /sec, which is reached at the midpoint of the specimen. Using this device rutting test can be performed on Air, Wet and Dry modes. These modes can be used by adjusting the device at desired test conditions. In this study specimens were tested using dry mode of wheel tracker.

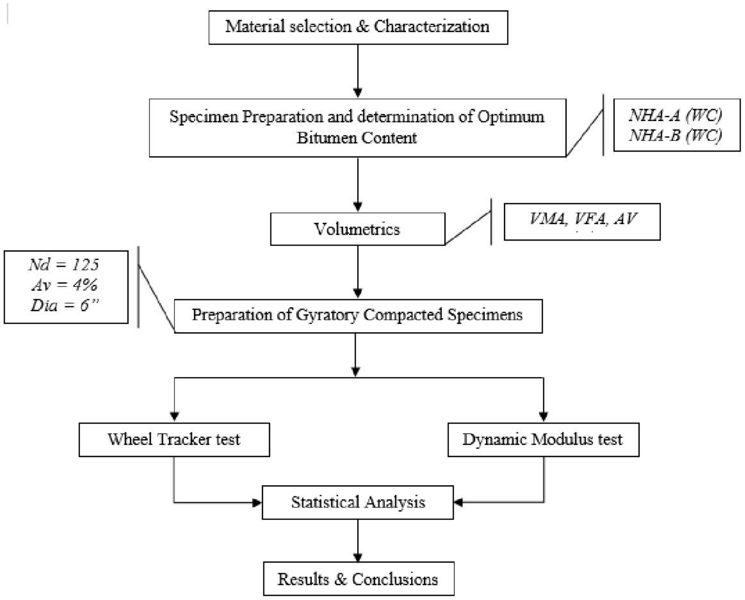

Figure 1: Flow Chart of Research Methodology

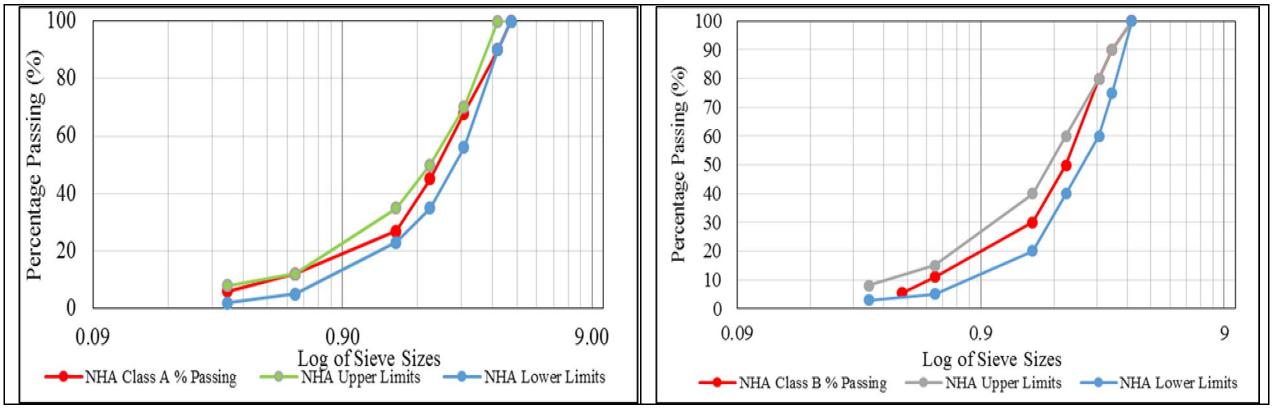

Figure 2: Gradation chart for HMA Mixtures

Table 1: Mix Volumetrics of HMA Mixtures

Gradation	Optimum Asphalt content	Air Voids (%)	VMA (%)	VFA (%)	%G$_{mm}$ @ N$_{initial}$	Dust to Binder ratio (%)
NHA-A	3.96	4.0	13.05	69.35	83.74	1.54
NHA-B	4.12	4.0	14.35	70.05	85.04	1.36
Modified NHA-A	6% Bakelite @ 3.96% OAC	4.0	13.54	69.45	87.35	1.54
Modified NHA-B	6% Bakelite @ 4.12% OAC	4.0	14.61	72.62	85.6	1.36

Dynamic modulus test was performed on Asphalt Mixture Performance Tester (AMPT). It consists of an environmental chamber, a tri-axial cell, a pump, a hydraulic actuator a refrigeration and heating unit with heat exchanger and a data acquisition system. The environmental chamber is capable of controlling temperature ranging from -4 to 60˚C and confining pressure unit is capable of providing pressure up to 210 kPa. The specimen is left to equilibrate for required test temperature in environmental chamber. After accomplishing desired temperature, tuning is done which yields initial modulus value which is to be input before running test. The UTS 6 software of SPT is used to run the test which automatically measure and record the test data. Triplicate specimens were tested for each mix at varying temperature (25 to 50˚C) and frequencies (0.1 to 25 Hz). After completion of both tests, the data was acquired from software and employed to statistical analysis.

4. Results and Analyses

This section presents the wheel tracker results, dynamic modulus results and statistical analysis carried out on the results for each gradation. Factorial design approach was used to determine the most effectual factor for dynamic modulus.

4.1 Wheel Tracker Test Results

From test results, rutting can be evaluated by comparing the rut depths obtained for controlled mixtures of both gradations with the bakelite-modified mixtures. Rut depth obtained after 20,000 passes was used to calculate the percentage improvement in specimen's resistance to rutting with the addition of bakelite. Table 2 shows the percentage improvement in rutting with the addition of bakelite for class A and class B mixtures. With the addition of bakelite (6%) in hot mix asphalt mixes of class - A along with the binder the resistance to rutting is improved largely.

Table 2: Rut Depth (mm) After 20,000 Passes

Mixture	Controlled Mixtures	Modified Mixtures	Improvement in Rut Depth (%)
NHA Class A Mixtures			
1	1.13	0.92	**18.6**
2	1.24	0.93	**25.0**
3	1.27	0.90	**29.1**
NHA Class B Mixtures			
1	1.34	0.93	**30.6**
2	1.42	0.95	**33.1**
3	1.57	0.97	**38.2**

From table 2 it is clear that after 20,000 passes the bakelite modified mixture's resistance to rutting is increased up to 29% as compared to the controlled mixtures. Similarly, with addition of bakelite (6%) in hot mix asphalt mixes of class -B along with binder the resistance to rutting is greatly improved. From table 2 it is clear that after 20,000 passes the bakelite modified specimen's resistance to rutting is increased up to 38% as compared to the specimens without bakelite modification. Figure 3 shows the graphical illustration of response of specimens with and without bakelite modification after rutting test.

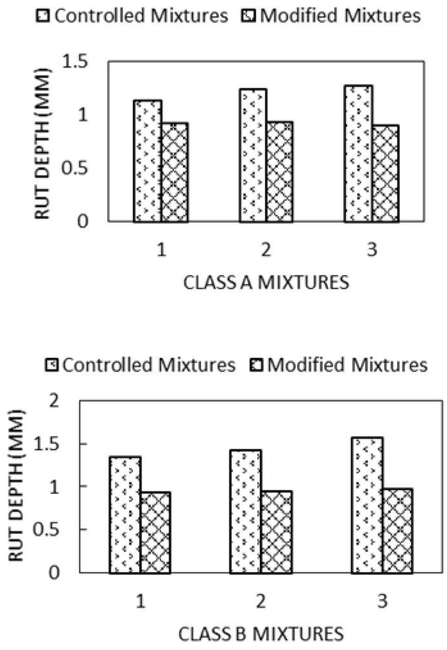

Figure 3: Graphical illustration of response of specimens with and without Bakelite modification after rutting test

4.2 Dynamic Modulus Test Results

The dynamic modulus values obtained for modified mixtures of both gradations were slightly higher as compared to dynamic modulus values of controlled mixtures. The results of both gradations i.e. NHA class A and B for controlled and modified mixtures were then compared separately to determine the percentage improvement in dynamic modulus with the addition of modifier. The comparison was carried out on dynamic modulus values obtained for all frequencies (25, 10, 5, 1, 0.5 and 0.1 Hz) and at temperatures 25, 40 and 50 ˚C. For modified mixtures of class A, with increase in temperature significant percentage increase in dynamic modulus values was observed as compared to controlled mixtures. Similar pattern was observed in modified mixtures of class B as compared to controlled mixtures are shown below in figure 4 and 5 respectively.

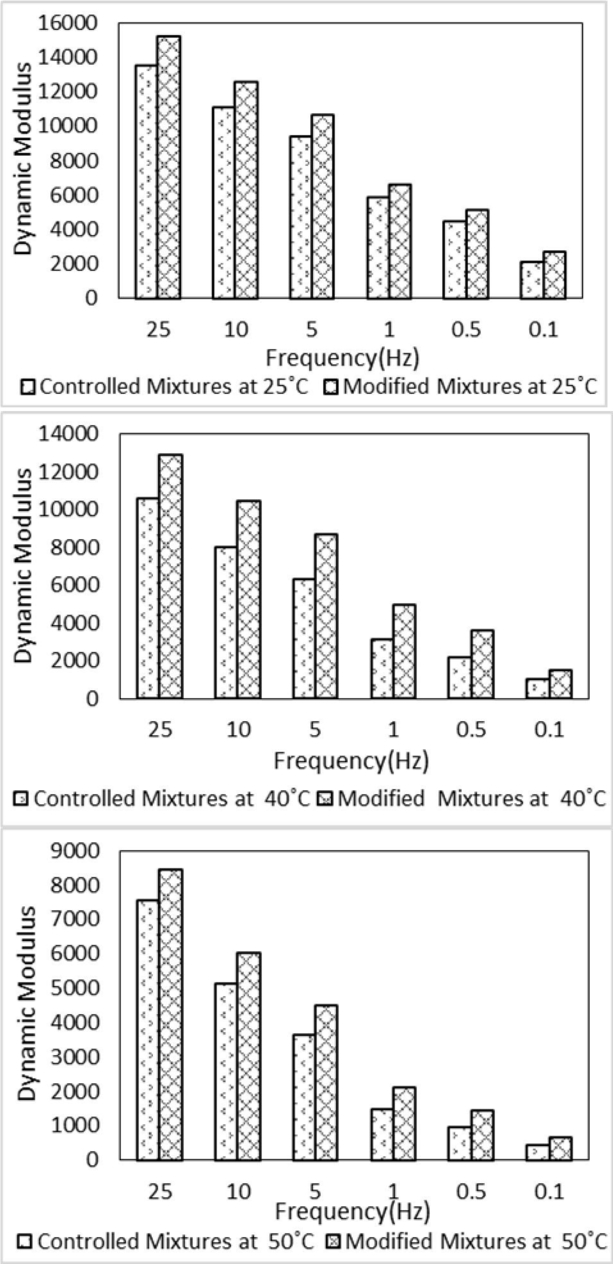

Figure 4: Dynamic Modulus of Class A Mixes

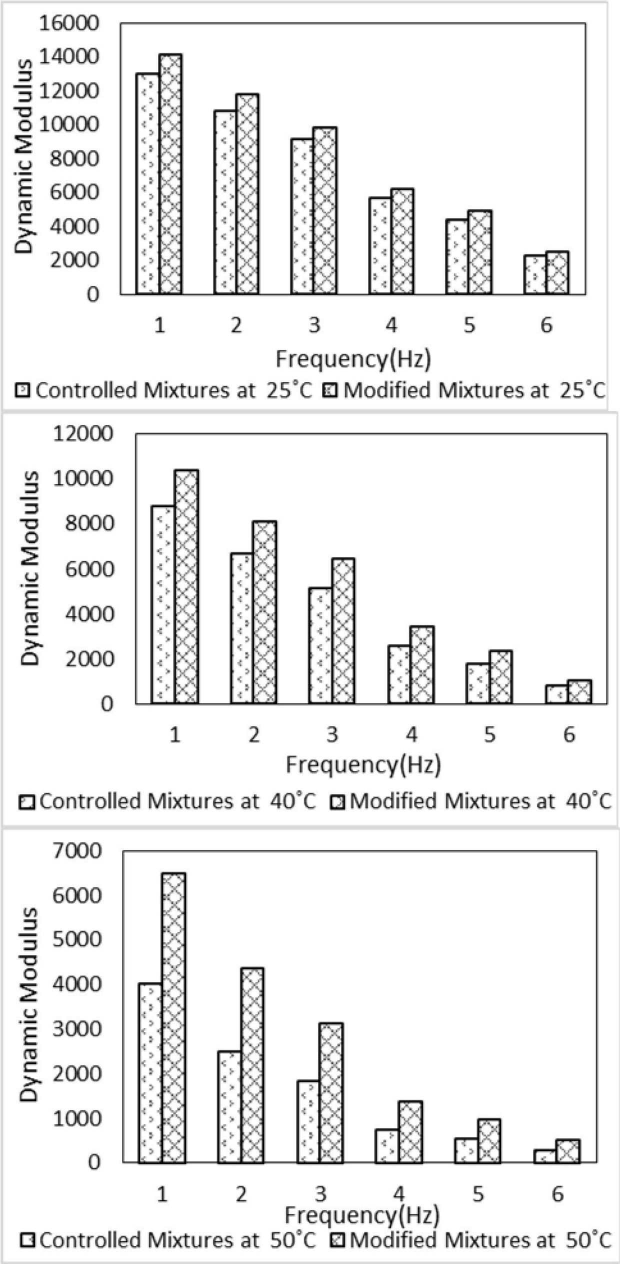

Figure 5: Dynamic Modulus of Class B Mixes

4.3 Statistical Analysis for Dynamic Modulus

A two level factorial design of experiment was conducted in order to determine the significant factors affecting the dynamic modulus. In this experiment, each parameter has two extreme values i-e high and low level. The factor considered for both types of mixes were temperature, frequency and Bakelite percentage. The table 3 illustrates the levels for factorial design along with abbreviation of each factor and measured unit. The temperature frequency and bakelite percentage remains same for all mixtures.

The effect can defined as it is mean difference in response of any factor at given two extreme values i-e low level and high level value, while interaction effect can be defined as mean difference between effect of one factor at extreme values i-e high and low level values of other factor or in other words, it can be said that it is difference of effect of one factor at high level of other factor and effect one factor at low level of other factor. It is also observed from factorial design software output that effect estimate is double the value of regression coefficient.

Table 3: Level of factors selected for analysis

Abbreviation	Factors	Levels		Units
A	Frequency	0.1	25	Hz
B	Temperature	25	50	˚C
C	Bakelite	0	6	%

The table 4 gives clear idea about significance of factors. The confidence level for said experiment was set as 95% hence significance level is α=0.05. The negative sign with effect shows that factor is inversely related to the response variable while positive sign indicates the direct relation of factor with response variable whereas the numerical value of effect shows the strength of effect to response variable. It can be inferred from said table that for wearing mixes temperature has negative effect on dynamic modulus which implies that with increase in temperature dynamic modulus value significantly drops and frequency is directly related with dynamic modulus which entails that with decrease in frequency dynamic modulus values also decreased. All these effects are significant as it can be seen by lower p-value.

Table 4: Main Effects and Interactions of Dynamic Modulus

Factors	NHA Class A W.C		NHA Class B W.C	
	Effects	P-Value	Effects	P-Value
A	9033	0.000	7587	0.000
B	-5359	0.000	-6723	0.000
C	1402	0.001	1211	0.001
A*B	-1563	0.011	-2426	0.000
A*C	470	0.347	638	0.137
B*C	-220	0.663	387	0.372
A*B*C	-147	0.808	329	0.525

The table 5 represents the analysis of variance for selected asphalt mixtures. Degree of freedom (DF) is three for main effect as three factors individually affect the response while in two factors interaction; DF is same as two factors combine and form three different combinations which explain variation in response and DF is one for three factors interaction as there is only one combination of three factors. The significance of effect can be represented by higher value of F and lower value of p. Also significance of factors can be estimated by value less than α=0.05.

Table 5: Analysis of Variance (ANNOVA) of Dynamic Modulus

Source	DF	Seq SS	Adj SS	Adj MS	F- test	P-value
NHA Class A Mixes						
Main Effects	3	1504061307	1445807008	481935669	146.15	0.000
2-Way Interactions	3	25443396	25629424	8543141	2.59	0.057
3-Way Interactions	1	195517	195517	195517	0.06	0.808
Residual Error	100	329755962	329755962	3297560		
Total	107	1859456182				
NHA Class B Mixes						
Main Effects	3	1342509350	1325509749	441836583	183.21	0.000
2-Way Interactions	3	60317691	61096783	20365594	8.44	0.000
3-Way Interactions	1	980362	980362	980362	0.41	0.525
Residual Error	100	241163670	241163670	2411637		
Total	107	1644971073				

Figure 6 shows the Pareto plot with absolute values of effects for class A and class B specimens with a reference line drawn, which shows the critical value of student-t (i.e. 1.98). The main factors i.e. Frequency, Temperature and Bakelite %age and the 2-way interactions i.e. frequency and temperature are beyond the reference line which indicates that these main effects and interactions (individual and 2-way) are critical and have influence on dynamic modulus of class A hot mix asphalt mixes at a significance level of 5%.

Figure 7 represents the main effect plot for HMA mixtures of class A class B mixtures. This figure expresses that main effect is plotted versus high and low levels of factors considered for study and the sharp slope of line shows that there is strong relation between parameter and response variable. It can be clearly seen from the plot between frequency and dynamic modulus that the value of dynamic modulus for class A mixtures is very high at 25 Hz frequency as compared to the value at 0.1 Hz frequency. The reason for this increase is that with increase in frequency more stresses are absorbed in specimen which results in an increased dynamic modulus value.

The plot between temperature and dynamic modulus shows that at lower temperature the value of dynamic modulus is high as compared to the dynamic modulus values at higher temperatures. The plot between dynamic modulus and bakelite %age shows a very mild slope. It may be due to the reason that at 0% bakelite the voids in mixes are more as compared to the voids at 6% bakelite as result of which fines are increased at 6% bakelite and voids are reduced so, the dynamic modulus values increase a little bit. Also the effect of this factor is not much significant. Similar trend is followed in the class B mixtures plots.

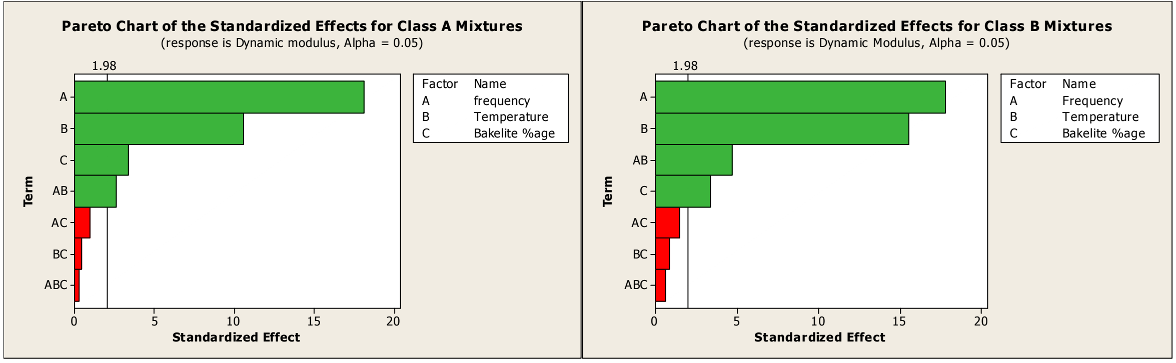

Figure 6: Pareto chart of standardized effects

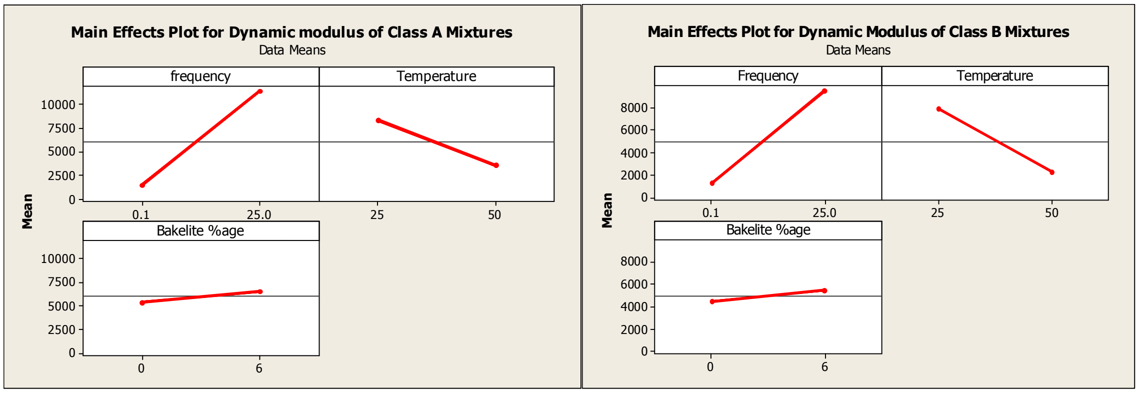

Figure 7: Main effect plot of factors affecting dynamic modulus

5. Conclusions

Based on Wheel Tracker Testing, Simple performance testing and analysis performed following conclusions can be made:

1. With addition of modifier, asphalt mixtures showed higher resistance to rutting.
2. Modified mixtures of NHA class B has the least rutting susceptibility as compared to the modified and controlled mixtures of both gradations.
3. 20 to 38% increase in rutting resistance is observed when bakelite is added.
4. Stiffness of mixtures increased significantly with addition of modifier.
5. Factorial design reveals that loading frequency is the most significant factor followed by test temperature and bakelite content.
6. The most significant two-way interaction is observed between loading frequency and test temperature

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