Effect of Lime on the Performance Evaluation of Asphalt Mixtures Using RAP in Pakistan

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Abstract

This study investigates the dynamic response $|E^*|$, rutting susceptibility and fatigue resistance of the virgin HMA and HMA blended with RAP and further RAP with hydrated lime mixtures. Optimum binder contents were obtained using Marshal Mix design method and the samples for performance testing were prepared. The Superpave Gyratory Compactor (SGC) was used. The samples were then cored and trimmed to the specified dimensions. Using Asphalt mixture performance tester (AMPT), test was conducted at four different temperatures (4.4, 21.1, 37.7 and 54.4) and six different frequencies (0.1, 0.5, 1, 5, 10 and 25). And flow tests were conducted at only one temperature of 54.4°C. The viscous properties of the mixture and the dynamic response indicators were brought into account to obtain the fatigue parameters to evaluate the fatigue resistance and from flow tests the rutting susceptibility was evaluated and the results showed that RAP and lime has weak resistance to fatigue but are less susceptible to permanent deformation. Master curves for all the mixtures were developed. HMA blended with RAP are very cost effective and environmentally friendly. The flow number results revealed that the virgin HMA accumulated more strains at less loading cycles as compared to the other mixes.

Keywords: Dynamic Modulus, Superpave, Flow number, RAP, Lime, HMA
I. Introduction

For decades now, to avoid the premature fatigue cracks and rutting, many researchers and agencies are focusing on improvement of pavement construction practices to minimize the rehabilitation and maintenance of existing pavements.

In Pakistan, the combined major road network has crossed the 260,000 kilometers mark and apart from few national highways all the pavements are asphalt concrete pavements. In flexible pavements, surrounding environment, fatigue cracking and rutting are the major causes of its deterioration. Due to these issues, the highway pavements fail before their design life. To maintain the existing highways to an acceptable level of service a huge amount of budget is allocated for rehabilitation and maintenance by highway agencies. For the past couple of decades, for developing countries like Pakistan, it is the most naturally desired way to rehabilitate the existing pavements timely with proper techniques because constructing new pavements need huge amount of capital cost. The easy survival lies in the cheap, recycled and sustainable methods, materials and techniques.

For producing more durable and high-performance pavements in the most cost-effective manner, pavement design is currently looking for more mechanistic based design approaches. Researches in pavement engineering has revealed that the highway design procedures are either empirical, which are based on results of experiments or experience, or the mechanistic design approach which mainly involves the material parameters at conditions as close as possible for what research is conducted, for analysis

II. Related Work

Dynamic modulus is the material property that knots stresses to strains which are induced under different time and temperature [II]. Initially its significance was very limited even many studies have revealed its importance. Its practical use in analysis and design of HMA by state highway agencies (AASHTO) was very less. In 2002, with the advent of new AASHTO design guide, the interest of researchers and designing agencies has increased due to the mechanistic-empirical approach which required dynamic modulus to accesses the responses of pavement and predict its performance under different conditions [III]. NCHRP 9-19 report opined that $|E^*|$ value is the fundamental material property and it should be the best indicator for distresses in asphalt pavements [IV]

The dynamic modulus is the basic design input and has the highest precision values[V]. At all three hierarchical levels in the new design guide, dynamic modulus is the primary material property[VI]. Various researches are in progress to obtain $|E^*|$ values for different regions and implement mechanistic-Empirical approaches. The pavement design is more about the mechanistic based design approaches for long lasting and high-performance pavements [VII]. MEPDG proposed dynamic modulus as an important and key input parameter which correlates the material properties to fatigue cracking and rutting behavior in the field.

Zhang et al examined the rutting and fatigue resistance using dynamic modulus test and revealed that the $|E^*|$ values of asphalt mixes remains constant with loading
cycles. $|E^*|$ values has a great effect on temperature and frequencies [VIII]. A research study on characterization of conventional HMA mixes using AMPT protocols opined that 3 factors has significant effect on dynamic modulus values are temperature, frequency and binder viscosity. In dynamic modulus testing revealed various factors which are aggregate, binder content and RAP which had great influence of dynamic response [IX].

Dynamic values increase with increase in mixture stiffness [X]. Witczak and Bari demonstrated in Arizona university research project that AASHTO 2002 design guide can be used effectively for lime modified asphalts and after investigation they found an overall 25% increase in dynamic modulus values with modified asphalt[XI]. A research conducted by Tao ma et al.[XII] using RAP in high modulus asphalt mixture and proves that when the RAP content is increased, the dynamic modulus and stability of recycling high modulus asphalt mixtures (RHMAM) increases while fatigue life decreases. It improves the rutting behavior but jeopardizes its low temperature cracking resistance, moisture stability and anti-fatigue property.

In Pakistan, the Marshall procedure and empirical approaches based on AASHTO 1993 design guide are used currently for bituminous mixture designs. For awareness and importance of MEPD approaches implementation this research has focused on performance testing of 3 different asphalt concrete mixtures using AMPT for dynamic modulus and flow tests. The results were further used to develop master curves and to estimate the fatigue resistance and rutting behavior.

### III. Methodology

The following paras explains the methodology which was adopted during the research

#### Materials Selection

In this study, to understand the effects of lime modification and RAP on dynamic modulus, experiments were performed on three (3) laboratory produced mixtures. The Pakistan’s national highway authority (N.H.A)’s B-class gradation was followed for all the mixtures[XIII]. The gradation of HMA mixes are presented in Table-1 and its graphical representation in Figure-1

| S. No | Sieve Size (mm) | %Passing | Our Selection | %Retained |
|-------|-----------------|----------|---------------|-----------|
| 1     | 19.0            | 100      | 100           | 0.00      |
| 2     | 12.5            | 75-90    | 82.5          | 17.5      |
| 3     | 9.5             | 60-80    | 70            | 12.5      |
| 4     | 4.75            | 40-60    | 50            | 20        |
| 5     | 2.38            | 20-40    | 30            | 20        |
| 6     | 1.18            | 5-15     | 10            | 20        |
| 7     | 0.075           | 3-8      | 5             | 4.50      |
| 8     | Pan             | …        | …             | 5.50      |

Table 1: NHA Gradation Class-B with Specified limit
Figure-1: NHA-B gradation with upper and lower limits

Marshall specimen of typical HMA mixes were prepared for the determination of volumetrics and optimum bitumen content (OBC) in accordance with American Society for testing and materials (ASTM D-6926)\[XIV\] Marshall sample with the same typical HMA OBC of the mix with varying percentages of RAP were prepared and tested. After determination of volumetrics, the most optimized sample of RAP was taken, and varying percentage of lime were added to it and same Marshall procedure for lime modified samples was repeated. 20% RAP and 3% lime modified mixtures were selected because of controlled volumetrics as per criteria shown in Table-2. The super gyratory samples were prepared for dynamic modulus and flow tests.

Table 2: Job mix formula Criteria

| Parameter     | HMA Measured Value | 20% RAP Measured Value | 20% RAP &3% Lime Measured Value | Criteria       | Remarks |
|---------------|--------------------|------------------------|---------------------------------|----------------|---------|
| VMA (%)       | 13.2               | 13.468                 | 15.003                          | 13 (min)       | Pass    |
| VFA (%)       | 69                 | 67                     | 66.153                          | 65-75          | Pass    |
| Stability (KN)| 12.5               | 14.5                   | 21.3                            | 8.006 (min)    | Pass    |
| Flow (mm)     | 2.7                | 2.3                    | 2.1                             | 2 - 3.5        | Pass    |
Sample preparation

The specimens were fabricated in super gyratory compactor and NCHRP 1-37A test method was followed. All the samples and its replicates are prepared. The dimensions of samples were 178mm (height) and 150mm (diameter). To get the uniform quality and volume trics distribution and keep the height to diameter ratio of 1.5, all the samples were initially cored and then cut to an average height of 150mm and diameter of 100mm [XV]. The samples and chamber both were conditioned at target temperatures.

Testing

For dynamic modulus testing, NCRHP 1-37A was followed and for each sample 3 replicates were prepared for testing. For all the samples, dynamic modulus tests were conducted at four temperatures (4.4, 21.1, 37.7, 54.4) and at six loading frequencies (25, 10, 5, 1, 0.5, 0.1) in descending order. A1min resting period was used so that the specimen can recover before the applying of new load. With the help of epoxy, strong enough to withstand against high temperatures, 3 studs were installed for the deployment of LVDTs (linear variable displacement transducer) at 120°C to each other for the recording of axial deformation and strains [XVI]. The samples were enclosed in environmental chamber to gain the required temperature according to AASHTO-TP-62-07 [XVII]. After achieving the required temperature, using UTS 6 software dynamic modulus test was conducted and the corresponding $|E^*|$ values and phase angle were obtained against temperature and frequencies. The flow tests were conducted at one temperature of 54.4°C. The test chamber was set at required temperature when both chamber and specimen reached that temperature, the sample of same 150mm height and 100mm diameter were placed in chamber and is allowed to gain the temperature loss before the test began. Assuming heavy traffic volume in Pakistan, 145KPA deviator stress was considered.

According to the standard the core specimen should have standard thickness and it’s both surfaces should be level and smooth. So after core cutting, a saw cutter was used to cut the core specimen to the standard thickness and its surface was also smoothing with the help of saw cutter. For ITFT and TSR test 4 inch and 1.5 inch thick core specimen was prepared having both the surface leveled.

V. Results/Discussion

The nature of HMA mixtures are Viscoelastic and phase angle shows the distinctive behavior of mixture. The results revealed that the phase angle is increased with increase in temperature and vice versa in case of frequencies as shown in Figure-2 (a, b, c). However, at higher temperature it starts behaving oppositely, it increases with increase in frequencies Figure 2(d). The past researches suggested that the elastic behavior of aggregates dictates the response of HMA at high temperature and low frequencies.
Figure 2(a, b, c, d) shows the variation of Phase angle with Frequency for all temperatures

**Dynamic Modulus**

Results obtained from dynamic modulus tests shows that the dynamic modulus is in direct relation with frequency and inversely proportional to temperature. With increase in temperature from 4.4 to 54.4 a decreasing trend in $|E^*|$ values was observed in all the samples Fig 3(a, b, c) which predicts that dynamic modulus test has greater sensitivity at higher temperatures and have higher variation coefficient than at lower temperature for almost all the mixes. Figure 4 (a and b) graphs are drawn at a single frequency (minimum and maximum frequencies) and different temperatures, which depicts a drop in dynamic modulus values with increasing temperature. This is because as the temperature increases the stiffness of the mix decreases and more strains are produced in response to the same applied stress resulting in a decreased dynamic modulus value. Moreover, RAP and lime samples has greater values of dynamic modulus than virgin HMA mixes Fig 3(a, b, c) at all temperatures because of its stiff
nature. Stiffness has a direct relation with dynamic modulus. RAP and RAP with lime showed 31% and 51% overall average increase in $|E^*|$ values.

Fig 3A: Dynamic Modulus Vs Frequency (21.1C)

Fig 3b: Dynamic Modulus vs Frequency (37.7C)

Fig 3C: Dynamic Modulus vs Frequency (54.4C)
Development of Master Curves

Master curves of HMA mixes allows comparison of different materials when they are tested at different frequencies. The dynamic modulus values were used to construct Master curves for all the mixtures using time-temperature superposition principle at a reference temperature, 21°C. The dynamic modulus values were shifted to the reference temperature to obtain a smooth uniform curve. Master Curve solver, Excel Sheet, was used to develop Master curve which was established under project 9-29 which minimize the sum of errors. The parameters and graphs obtained for all the samples are shown in Table-3 and Figure-5(a, b, c).

Table 3: Parameters obtained for all mixes

| Parameters | Virgin HMA | RAP | RAP+ Lime |
|------------|------------|-----|-----------|
| A          | 0.59       | 0.81| 0.90      |
| B          | -1.81      | -1.88| -1.89     |
| Γ          | 0.71       | 0.78| 0.71      |
| C          | 0.78       | 0.74| 0.79      |
Figure 5(a) Master Curve for Virgin Mixes

Figure 5(b) Master Curve for RAP Mixes
Figure 5(c) Master Curve for RAP with Lime Mixes

Figure 5(a, b, c) represents the master curves for all the three mixes. The graph shows that lime modified mixes (Fig 5-c) has the highest dynamic modulus values at all frequencies even at high temperatures which shows its ability to resist permanent deformation while virgin HMA (Fig 5-a) has the lowest values at all the frequencies and temperatures which shows the sensitivity to modifying the volumetrics. At moderate temperatures the virgin curve was smooth which shows its ability to resist fatigue cracking. At extreme temperatures all the mixtures tend to merge at single point.

**Estimation of Fatigue Resistance**

To evaluate fatigue resistance the fatigue parameters can be obtained from dynamic modulus values [XVIII]. It is the product of |E*| and phase angle which shows the viscoelastic behavior of the mix. The fatigue parameter is given by

\[ \text{Fatigue Parameter} = |E^*| \times \sin \alpha \quad \text{Eq1} \]

where in Eq 1 |E*| is dynamic modulus and \( \alpha \) is phase angle.

Fatigue parameter is inversely proportional to fatigue resistance. Hence greater fatigue parameter value will provide very low resistance to fatigue cracking. All the samples were compared at 21°C with varying frequencies for fatigue cracking because the fatigue crackings are more sensitive at moderate temperatures. At higher temperatures, the mixes are more prone to permanent deformation (Rutting) Table-4.2 and 4.3 shows that RAP and Lime has high fatigue parameters than Virgin HMA (Table 4.1) hence their resistance to fatigue cracking is low. This could possibly be due to its stiff nature as fatigue resistance is inversely proportional to stiffness. Contrary to them virgin HMA showed greater resistance to fatigue cracking as their fatigue parameters values are low. Fig-6 shows the comparison of fatigue parameters at different frequencies of all the mixes at 21°C.
Table 4.1: Fatigue parameters of Virgin HMA at 21C

| Type     | Temperature | Frequency | Fatigue Parameter |
|----------|-------------|-----------|-------------------|
| Virgin HMA | 21          | 0.1       | 730.50            |
|          |             | 0.5       | 1172.79           |
|          |             | 1         | 1429.21           |
|          |             | 5         | 1707.89           |
|          |             | 10        | 1946.58           |
|          |             | 25        | 2172.85           |

Table 4.2: Fatigue parameters of RAP at 21C

| Type | Temperature | Frequency | Fatigue Parameter |
|------|-------------|-----------|-------------------|
| RAP  | 21          | 0.1       | 905.56            |
|      |             | 0.5       | 1487.14           |
|      |             | 1         | 1811.76           |
|      |             | 5         | 2595.67           |
|      |             | 10        | 2913.23           |
|      |             | 25        | 3149.86           |

Table 4.3: Fatigue parameters of Lime at 21C

| Type | Temperature | Frequency | Fatigue Parameter |
|------|-------------|-----------|-------------------|
| Lime | 21          | 0.1       | 1123.83           |
|      |             | 0.5       | 1761.99           |
|      |             | 1         | 2098.15           |
|      |             | 5         | 2847.13           |
|      |             | 10        | 3148.90           |
|      |             | 25        | 3391.87           |

Fig 6: Fatigue Parameters comparison of all mixes
Cost Effectiveness

With 20% optimized use of RAP and 3% lime, in HMA mixes, the Marshall test volumetrics were quite in range as per standard practice and showed good results against permanent deformation with greater $|E^{*}|$ values than virgin HMA. Cost analysis were done for HMA mixes with and without addition of RAP and Lime for 1KM typical road section. The analysis showed that with 20% RAP the mixes were very economical. For cost effective design technique, the proper gradation, preservation and saving of precious aggregates reclaimed asphalt pavements (RAP) recycling is one of the critical needs which also not only reduces the cost of expensive binder but is also very environmentally friendly because of less CO2 emissions. Fig-7 shows that 1KM typical road section can approximately saves 1.6millions with RAP in Pakistan. Studies shows that Pakistan’s highways are more prone to permanent deformation. Our study suggests that RAP with optimum (3%) lime is very cost effective as it showed better results against rutting.

![Cost Comparison of all mixtures](image)

**Figure 7:** Cost comparison of all mixtures

Flow Number

The flow number results evaluate the rutting susceptibility. The tests were conducted at high temperature of $54.4 \, ^\circ C$ because at higher temperatures HMA mixes are more susceptible to rutting. The flow number graphs for all the three mixes are presented in Fig-8 which shows that softer mixtures (Virgin HMA) accumulated more strains at less loading cycles while mixtures containing RAP and Lime accumulated less strains at greater loading cycles which shows its stiff behavior. It is suggested from flow number results that virgin HMA is more susceptible to permanent deformation.
The results obtained from Tensile Strength Ratio Test, Indirect Tensile Fatigue Test were compiled to investigate the effect of Reclaimed Asphalt Concrete (RAP), Crum Rubber and the combination of both at different percentages on different pavement distresses i.e. Fatigue and moisture resistance. The screened data was further analyzed to find out the effectiveness of RAP, Crum Rubber and both, as fatigue resistant agent to reduce alligator cracking and to reduce the moisture damage of Hot Mix Asphalt (HMA) pavement.

VI. Conclusion

Following are the conclusions of the research

- RAP and lime have great effect on dynamic modulus values which is the basic key input in pavement design process.
- RAP and lime are less susceptible to permanent deformation, root cause of pavement deterioration in Pakistan.
- Virgin HMA shows greater resistance to fatigue.
- Test temperatures and loading frequencies are the most significant features in dynamic modulus test.
- Phase angle increases initially and then drop immensely at the peak temperatures.
- RAP and Lime accumulates less strains at maximum cycles.

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I. AASHTO, T.I.S.S.f.T.M., M.o. Sampling, and Testing. Standard method of test for determining dynamic modulus of hot-mix asphalt concrete mixtures. 2005.

II. Bari, J., Development of a new revised version of the Witczak E* predictive models for hot mix asphalt mixtures. 2005, Arizona State University Tempe, AZ.

III. Bayane, B.M., et al., Dynamic Modulus Master Curve Construction Using Christensen-Anderson-Marasteanu (CAM) model. 2017. 7(1): p. 53-63.

IV. D. A. Standard practice for preparation of bituminous specimens using Marshall apparatus. 2010. American Society for Testing and Materials USA.

V. Dougan, C.E., et al., E*-dynamic modulus: test protocol-problems and solutions. 2003.

VI. Ekwulo, E.O., D.B.J.A.J.o.E.S. Eme, and Technology, Fatigue and rutting strain analysis of flexible pavements designed using CBR methods. 2009. 3(12).

VII. Flintsch, G.W., et al., Asphalt materials characterization in support of implementation of the proposed mechanistic-empirical pavement design guide. 2007, Virginia Center for Transportation Innovation and Research.

VIII. Gul, M.A., Laboratory characterization of HMA mixes subjected to indirect tensile fatigue test. 2015, NUST.

IX. Ma, T., et al., Using RAP material in high modulus asphalt mixture. 2015. 44(2): p. 781-787.

X. Olidis, C. and D. Hein. Guide for the Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures Materials Characterization: Is Your Agency Ready. in 2004 Annual Conference of the Transportation Association of Canada. 2004.

XI. Pellinen, T.K. and M.W.J.J.o.t.A.o.A.P.T. Witczak, Stress dependent master curve construction for dynamic (complex) modulus (with discussion). 2002. 71

XII. Seo, J., et al., Estimation of in situ dynamic modulus by using MEPDG dynamic modulus and FWD data at different temperatures. 2013. 14(4): p. 343-353

XIII. Specifications, N.G.J.L., Pakistan. National Highway Authority, prepared by SAMPAK International (Pvt.) Ltd. 1998.

XIV. Witczak, M. and O.J.T.R.R.J.o.t.T.R.B. Fonseca, Revised predictive model for dynamic (complex) modulus of asphalt mixtures. 1996(1540): p. 15-23.

XV. Witczak, M. and J.J.A.S.U.R.R. Bari, Tempe : Arizona State University, Development of a master curve (E*) database for lime modified asphaltic mixtures. 2004.

XVI. Yu, H. and S.J.R.N.T. Shen, An investigation of dynamic modulus and flow number properties of asphalt mixtures in Washington State. 2012. 2.

XVII. Ye, Q., S. Wu, and N.J.I.J.o.F. Li, Investigation of the dynamic and fatigue properties of fiber-modified asphalt mixtures. 2009. 31(10): p. 1598-1602.

XVIII. Zhang, Y., R. Luo, and R.L.J.J.o.M.i.C.E. Lytton, Characterizing permanent deformation and fracture of asphalt mixtures by using compressive dynamic modulus tests. 2011. 24(7): p. 898-906.