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Evaluation of Permanent Deformation and Fatigue using Lime Modified Binder

Engr.Haseeb Ali Khan [#1], Dr. Arshad Hussain [*2]

[#1] Postgraduate Student, National Institute of Transportation,
National University of Sciences & Technology (NUST), Islamabad, Pakistan

[#2] Assistant Professor, National Institute of Transportation,
National University of Sciences & Technology (NUST), Islamabad, Pakistan

[1] engr.haseeb_official@hotmail.com

[2] arshad_nit@yahoo.com

Abstract— Hot mix asphalt (HMA) pavements are exposed to repeatedly variations in traffic loads and environmental conditions. When imposed stresses are coupled with environmental actions that are caused owing to frequent traffic loads, a reduction in pavement life occur due to moisture damage. Resultantly, it formed permanent deformation and cracking failures. In order to avert this harm, anti-stripping additive are used to increase adhesion of the aggregate-asphalt interface. In this research, lime -the most common solid anti stripping additive- is used .The study targets to evaluate the permanent deformation and fatigue cracking of lime modified asphalt mixtures through Hamburg Wheel Tracking (HWT) laboratory test and Indirect Tensile Fatigue Test (ITFT). The overall findings concluded that lime modified mixtures shows better results than that of unmodified asphalt mixtures in performance test.

Keywords: Asphalt Mixtures, Permanent Deformation, Lime, Hamburg Wheel Tracker Test (HWT), Indirect Tensile Fatigue Test (ITFT)

I. Introduction

The roadway network plays an indispensable role in socio-economic growth of a country, Moreover, with the onset of globalization and burgeoning population, the road congestion increases because of the ownership of vehicle and development of world transportation. This kind of situation increases the volume of traffic, traffic loads and tire pressure. Resultantly, these factors would play a pivotal role in pavement deformation such as the rutting and fatigue cracking. In hot mix asphalt pavements, asphalt is an indispensable part of wearing surface of road structure because it plays pivotal role as a binder so, it has been modified a number of times against its failure [1]. In hot-mix asphalt (HMA) mixtures, owing to distinct stiffening effects of lime, it decrease rut-depth of pavement and also improves bond between aggregate and asphalt [2]. Hydrated lime addition both in wet and dry mode is quantified. In dry mode, 1.5% lime was added to that of dry aggregate and in wet mode, 20-30% lime was added to that of asphalt binder weight [3]. Moreover, one of an indispensable benefit of lime is that it has the lowest environmental footprints as compared to simple HMA mixtures [4]. The laboratory examination of lime modified binder concluded that the stability increase with the increases of hydrated lime in the mixture [5]. Furthermore, addition of lime resists the deformation at approximately all temperatures but showed good results at 40 degree temperature [6]. Besides, on the other hand, fatigue cracking is also a problem of concern in the performance and design of hot mix asphalt (HMA) pavements since the hot mix asphalt pavements are being used. Owing to repeated number of traffic loads, structural failure occurs in the pavements that causes fatigue cracks [7].

II. Objectives And Scope

A comprehensive research plan was prepared and following research tasks were outlined. Literature review on the previous researches has been carried out. Specimens were prepared in the laboratory to find optimum asphalt content using superpave gyratory compactor in order to find the volumetric properties of the gyratory samples. Hydrated lime with different percentage including 1%, 1.5% and 2% is used in samples and volumetric properties were find out. Furthermore, 1.5% hydrated lime-as significant percentage after determination of volumetric properties- is used in the laboratory samples and performance tests were carried out through Hamburg Wheel Tracker test. Finally results were compared with un-modified samples. Penetration grade 60/70 and superpave 19mm and 25mm gradation were used. 1.5% lime was added in the dry state to total weight of dry aggregate. On gyratory compacted samples, Hamburg Wheel Tracker Test was conducted at 40^{o}C.

On the other hand, the research included the Indirect Tensile Fatigue test on gyratory compacted samples performed on two gradations i.e Superpave 19mm and 25mm modified with lime. Testing were conducted on two different temperatures i-e 25 °C and 40 °C and the load applied on the samples were taken 2500N. There were two replicate samples tested for each gradation both conventional and unconventional for both the temperatures.

III. RESEARCH METHODOLOGY

The research was conducted in three phases. Initially, different aggregate sizes including 0-5mm, 5-10mm, 10-20mm were collected through Margalla Quarry. Bitumen source was Attock Refinery Limited (ARL) and penetration grade 60/70 was selected to be used. The reason for selecting the penetration grade 60/70 is that it is the commonly used bitumen grade across Pakistan. After selection of material, next task was to characterize the material according to reference specifications.

For both gradations, the samples were prepared according to superpave mix design manual (SP-2) in order to determine optimum asphalt content. In this way, binder with 3-4.5% with an interval of 0.5 is used and samples were prepared in gyratory compacter. Each sample weights approximately 4500 gram. The volumetric parameters theoretical maximum specific gravity Gmm, effective specific gravity Gse, Bulk specific gravity Gmb and %Gmm of prepared specimens were measured, verified in light of Superpave mix design criteria and finally optimum asphalt contents were determined.

In the second phase, for determining the optimum asphalt content, bituminous paving mixes were prepared according to the method explained in Asphalt Institute’s Superpave mix design manual (SP-2). HMA samples were prepared using 0%, 1%, 1.5% and 2% of lime**.** These percentages of lime were added in account of total dry weight of aggregate. The optimum asphalt content for each was determined by repeating the Superpave mix design procedure two times. The volumetric properties of mix including, air voids (Va), voids in mineral aggregates (VMA) and voids filled with asphalt (VFA) were determined using their respective formulae after determination of theoretical maximum specific gravity (Gmm) and bulk specific gravity (Gmb). Theoretical maximum specific gravity (Gmm) and bulk specific gravity (Gmb) were determined in accordance with AASHTO T209 and AASHTO T166 respectively.

The size of the samples prepared in the gyratory compactor used is 6 inch (150 mm) in diameter and 7 inch (177.8 mm) in height. After the samples were compacted using the gyratory compactor the samples were left for 24hr to come to the room temperature. Once the samples were at room temperature core cutting machine accompanied by the saw cutting machine was used to core out 4 inch (100 mm) diameter specimens from the 6 inch (150 mm) samples. Further the saw cutting machine was used to cut the specimens into the required thickness, at least 1.57 inch (40 mm) for Indirect Tensile Fatigue Test as instructed in EN 12697 – 24 and 150 mm for wheel tracker test respectively.

In the third phase, the samples were tested in order to find the rut depth and number of cycles to failure of the specified specimen using Hamburg Wheel Tracker (HWT) and Universal Testing Machine (UTM). HWT was performed according to AASHTO T 324-04 standard and the number of passes on the specimens was fixed to 20,000. Wet mode of wheel tracker device was selected at 40 degree centigrade. Finally the test was run and wheel started moving to and fro on the mounted specimen. One complete to and fro movement of the wheel was taken as 2 passes. The indirect tensile fatigue test was conducted according to EN-12697-24 standard on the cylindrical shaped samples to characterize modified and unmodified HMA mixes under repeated load applied with constant load mode. The cylindrical shaped test samples are subjected to repeated compressive load in the vertical direction. . The testing was performed for 25 °C and 40°C with a load of 2500N. The samples were tested in Universal Testing Machine UTM 25.

IV. ANALYSIS AND RESULTS

Test results of Indirect Tensile Fatigue test and wheel tracker tests are presented in this section. Statistical Analysis done on Indirect Tensile Fatigue test in order to obtain the significant factors is also presented in this section.

A. *Wheel Tracker Test*

Rutting can be assessed by comparing the rut depths obtained for controlled mixtures of both gradations with the lime-modified mixtures. Result of Hamburg Wheel Tracker test of 19mm gradation is shown in figure 1. It is cogent from the figure that for 19mm gradation, the rut depth value of modified sample is 3.57mm for sample 1 and 3.63mm for sample 2. On taking average of both the values, the average rut depth became 3.6mm. On the other hand, the values of unmodified samples were 4.27mm and 5.02mm and their average became 4.645mm. Conclusively, it showed that average improvement in 19mm gradation with 1.5% lime was notes as 22.04%. The graphical illustrations of 19mm gradation test results are shown in figure 1.

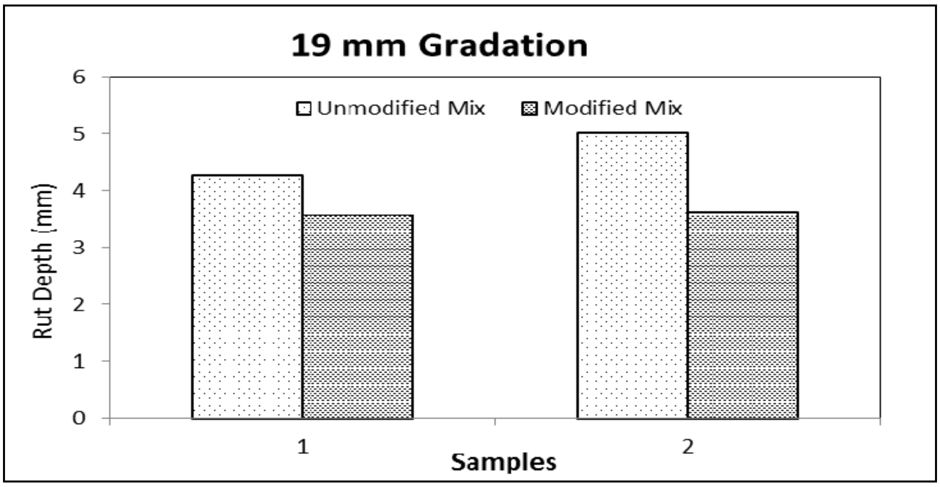

Figure 1: Rut Depth of 19mm Gradation at 40^{o}C

Likewise, results of Hamburg Wheel Tracker test of 25mm gradation also showed better results of samples that are modified with lime. For 25mm gradation, the rut depth value of modified sample is 1.87mm for sample 1 and 1.29mm for sample 2. The average rut depth of modified samples was 1.58mm. Furthermore, the values of unmodified samples were 3.64mm and 2.97mm and their average became 3.305mm. Finally it showed that average improvement in 25mm gradation with 1.5% lime was notes as 52.14%.. The graphical illustrations of 25mm gradation test results are shown in figure 2.

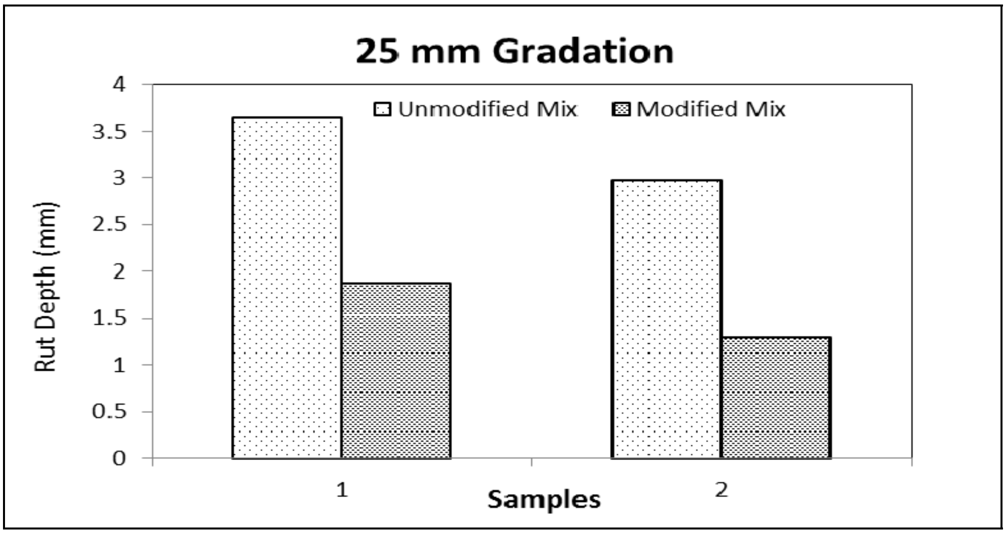

Figure 2: Rut depth of 25mm Gradation at 40^{o}C

B. Indirect Tensile Fatigue Test

The research included the performance test of Indirect Tensile Fatigue that was performed on two gradations that were modified with lime. Testing were conducted on two different temperatures i-e 25 °C and 40 °C and the load applied on the samples were taken 2500N.

It is cogent from the figure 3 that for 19mm gradation, the number of cycles to failure of modified sample is 16839 for sample 1 and 15548 for sample 2. On taking average of both the values, the average value became 16193. On the other hand, the values of unmodified samples were 13169 and 14669 and their average became 13919. Conclusively, it showed that average improvement in 19mm gradation with 1.5% lime was notes as 15-18%. The graphical illustration of 19mm gradation at 25^{o}C is shown in figure 3.

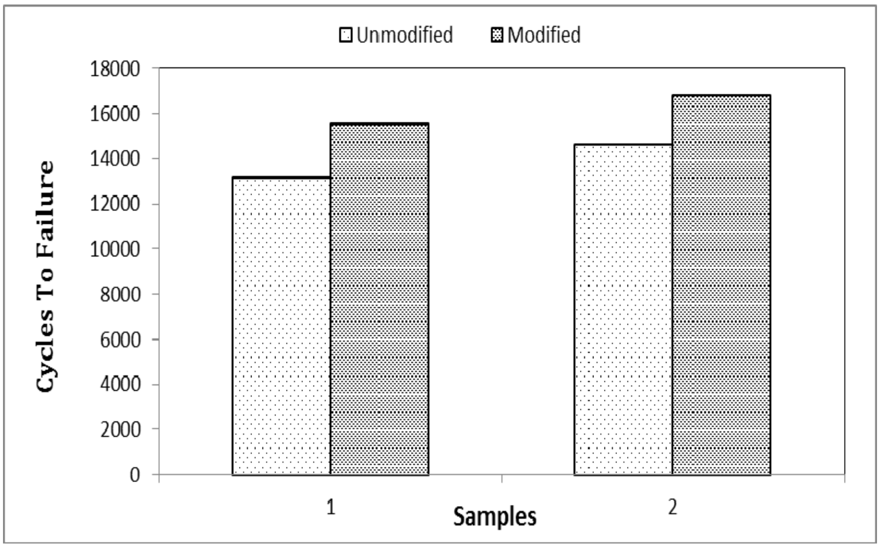

Figure 3: Number of Cycles to failure of 19mm Gradation at 25°C

For 25mm gradation, the number of cycle to failure value of modified sample is 23459 for sample 1 and 20945 for sample 2. The average value of modified samples was 22202. Furthermore, the values of unmodified samples were 19473 and 18979 and their average became 19226. Finally it showed that average improvement in 25mm gradation with 1.5% lime was notes as 10-20%. For 25mm gradation at 25°C, figure 4 illustrates fatigue resistance of modified samples than that of unmodified samples.

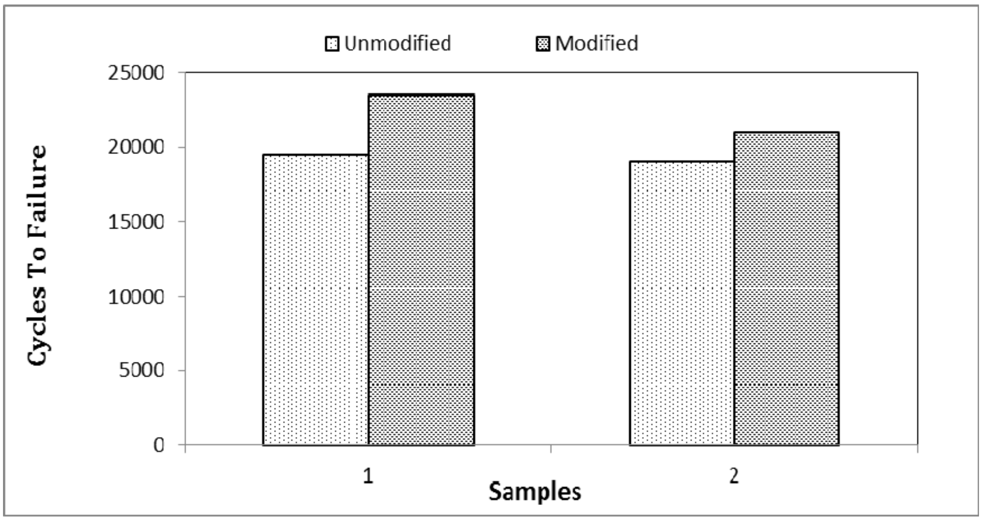

Figure 4: Number of Cycles to failure of 25mm Gradation at 25°C

On the other hand, at 40° C for 19mm gradation, the number of cycle to failure value of modified sample is 2739 for sample 1 and 2549 for sample 2. The average value of modified samples was 2644. Furthermore, the values of unmodified samples were 2019 and 1979 and their average became 2044. Finally average improvement in 25mm gradation with 1.5% lime was noted as 29-30% in figure 5.

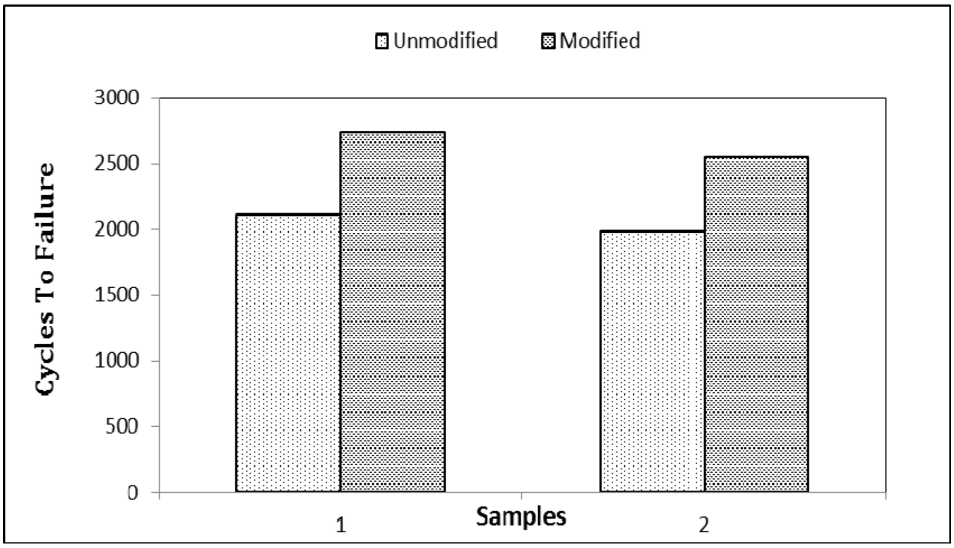

Figure 5: Number of Cycles to failure of 19mm Gradation at 40^{o}C

Similarly at 40^{o}C for 25mm gradation, the number of cycle to failure value of modified sample is 3879 for sample 1 and 3459 for sample 2. The average value of modified samples was 3669. Figure 6 shows the cycle to failure of 25mm gradation at 40^{o}C. The values of unmodified samples were 3059 and 3019 and their average became 3039. Finally it showed that average improvement in 25mm gradation with 1.5% lime was notes as 15-27%.

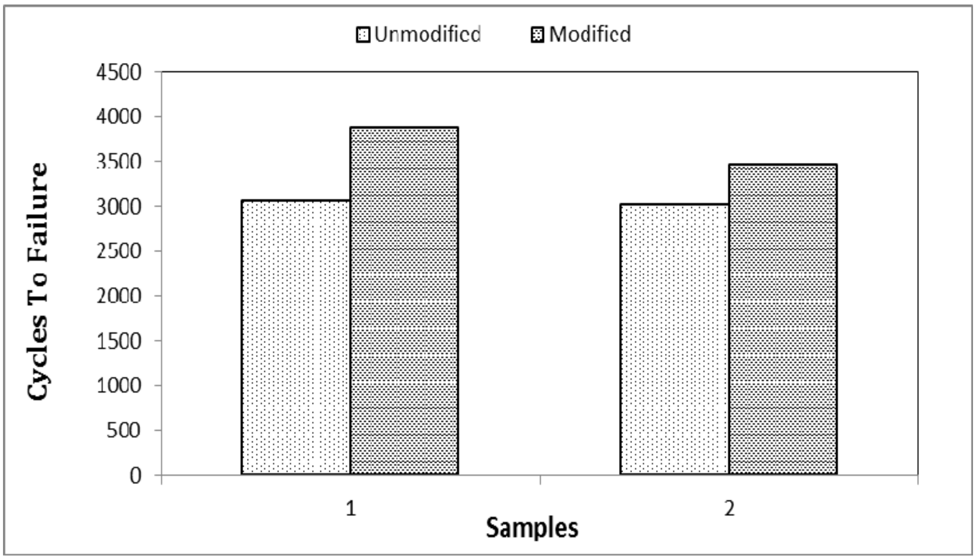

Figure 6: Number of Cycles to failure of 25mm Gradation at 40^{o}C

4. *Statistical Analysis of Indirect Tensile Fatigue Test*

The statistical analysis of ITFT data with and without lime modification was performed by considering three factors i.e. gradation, test temperature and lime percentage each with two levels. Therefore, 2^3 full factorial design of experiment was performed using MINITAB-15 software. Table 1 shows the factors that have been considered in the factorial design with their high and low levels and abbreviations.

Table 1: Factors and their Level for Factorial Design

Notations	Parameters	Low	High	Units
1	Gradation	19	25	Mm
2	Temperature	25	40	^{o}C
3	Lime	0	1.5	%

5. Significant Effects

In terms of Normal probability plot and Pareto plot generated using Minitab 15 software, the factors and interaction of factors, which are most significant and affect fatigue cracking of asphalt mixtures, are also shown. Figure 7 shows the Pareto plot having a reference line with red color which shows that beyond this reference line a significant variable came up and have greater effect on the fatigue cracking. It is obvious that, temperature showed significant result and have greater influence on fatigue cracking of lab prepared mixtures at 5% significance level. The other plot is the normal probability plot which also shows the significant main effect as shown in figure 8 respectively. In the normal probability plot the factors or interactions away from the reference line are significant at 5% significance level and the factors which are near the reference line or on the reference line, are insignificant.

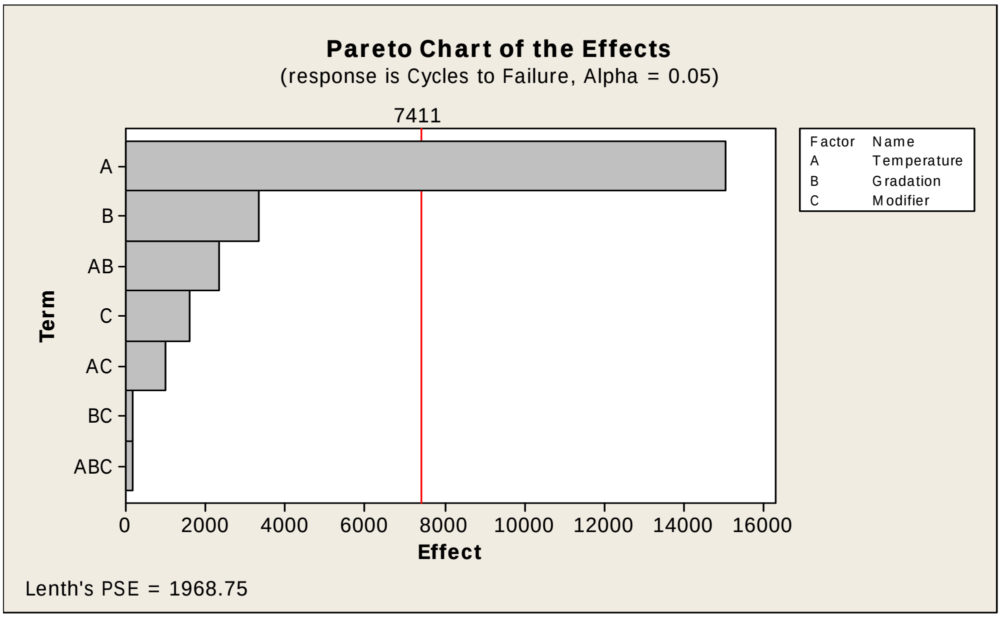

Figure 7: Pareto Chart

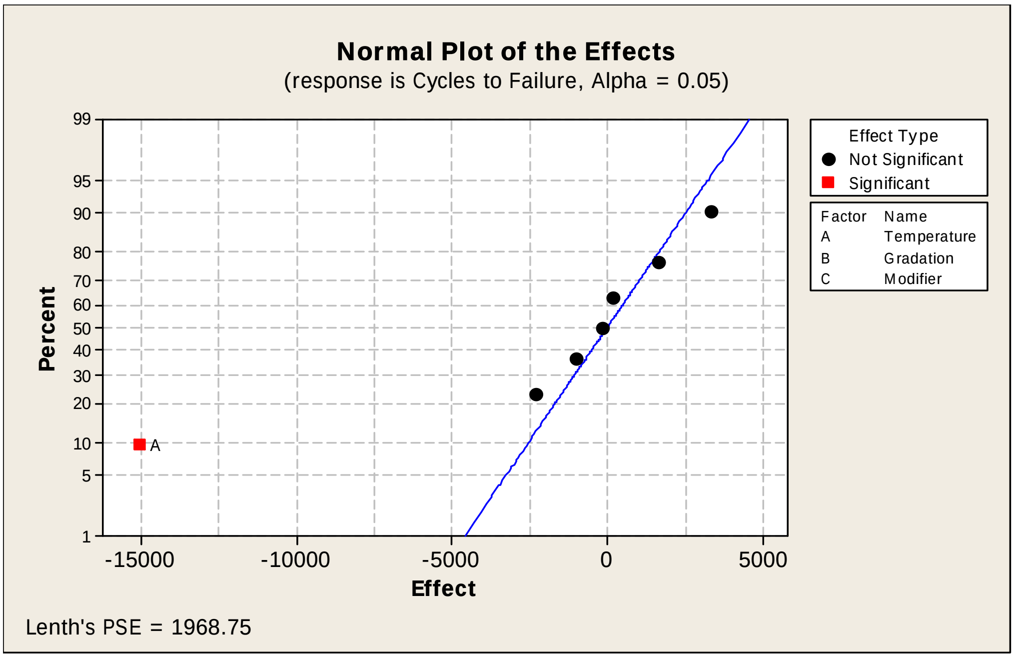

Figure 8: Normal Chart of Samples

6. Main Effect Plots

The effects of gradation, temperature and lime %age of lab Prepared specimens are shown in figure 9 respectively. The graph between temperature and fatigue cracking reveals that with increase in temperature the number of cycle to failure decreases.

The graph between fatigue cracking and gradation indicates direct relationship i.e. the number to cycle failure increases if nominal maximum aggregate size increases.

So from this analysis it is quite obvious that the temperature has greater effect on fatigue cracking as in the below figure, it is clear that the slope of temperature vs number of cycles is greater. Moreover, nominal maximum aggregate size has also greater impact on fatigue cracking as it also showed greater slope. At last, modifier also showed impact on fatigue cracking behavior as its slope in the figure is also liner and inclined that showing effects on fatigue cracking.

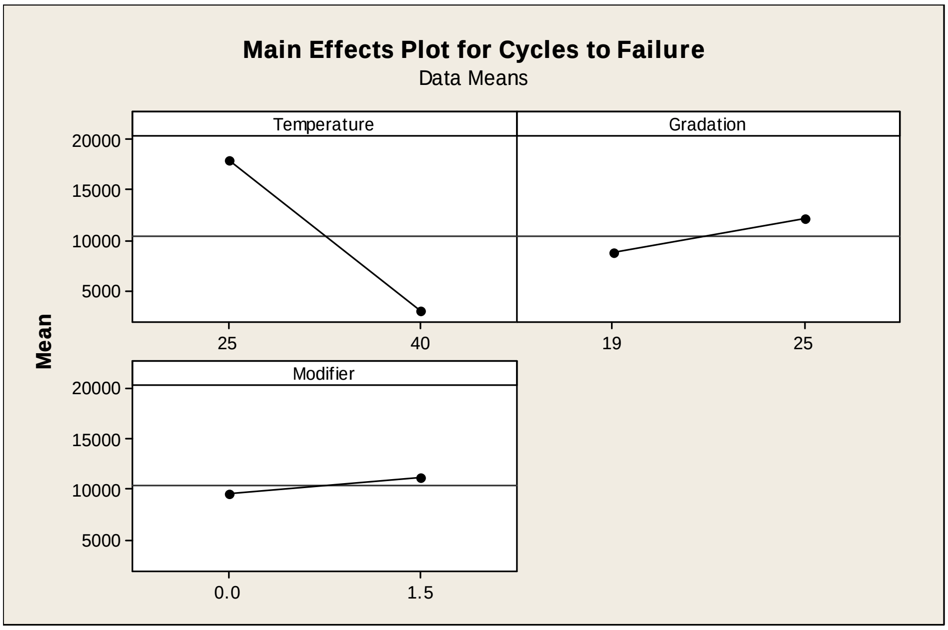

Figure 9: Main Effects Plot

V. Conclusion

The conclusions drawn from the analysis of tests as mentioned in chapter 4 are classified as follow:

- At 40^o C, the use of 1.5% lime in asphalt mixtures increases rutting potential to approximately 16-29% as compared to unmodified asphalt mixtures for 19mm gradations.
- For 25mm gradation, lime modified binder showed 48-55% better results than that of unmodified samples at 40^{o}C.
- With modification of lime the asphalt mixtures shows higher resistance to fatigue cracking at both 25^o C and 40^o C.
- At 25^{o}C, improvement in fatigue cracking is observed in 19mm gradation in lime modified mixtures whereas 22% improvement in fatigue cracking is also observed for 25mm gradation.
- At 40^{o}C, improvement in fatigue cracking is observed in 19mm gradation in lime modified mixtures whereas 22% improvement in fatigue cracking is also observed for 25mm gradation.
- Statistical analysis shows that temperature is the most significant factor which affects the indirect tensile fatigue test values followed by gradation and lime content.

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