

# Investigation of Hydrated Lime Effect in Asphalt Pavements

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**Abstract-** Hydrated lime (HL) has been added to hot mix asphalt pavements over the years to improve the asphalt concrete mixtures in many ways. Although it has been repeatedly shown that the use of hydrated lime in asphalt concrete mixtures is beneficial, confusion still exists about the appropriate methods of adding hydrated lime to the mixtures to achieve the optimum modification of hydrated lime. The reasons why hydrated lime is so effective in asphalt mixtures lie in the strong interactions between the major components such as aggregate and bitumen. In this study, effects of hydrated lime in the asphalt pavements are investigated by performing Marshall Stability test, indirect tensile strength test, moisture susceptibility test and resilient modulus test. It can be concluded that, the addition of hydrated lime generally improved the fatigue properties of the asphalt mixture regardless the method of application to the mixtures. Asphalt mixtures modified with hydrated lime using wet method showed better properties as compared to mixtures modified with hydrated lime using dry or slurry methods. Overall description aids that the wet method is better than dry or slurry methods despite the little effect on Marshall, Moisture Susceptibility test results when comparing all the test results and seems to provide better performance for pavement.

**Keywords-** Asphalt mixtures, Hydrated lime, Marshall test, Indirect tensile test, Resilient modulus test, Moisture susceptibility

## I. INTRODUCTION

Hydrated lime has been added to hot mix asphalt pavements over the years, improving the asphalt concrete mixtures in many ways. Although it has been shown repeatedly that the use of hydrated lime in asphalt concrete mixtures is beneficial, confusion still exist about the appropriate method of adding hydrated lime to the mixtures to achieve the optimum modification of hydrated lime. Hydrated lime has been known as an additive for asphalt mixtures from their very beginning. It experienced a strong interest during the 1970s in the USA, partly as a consequence of a general decrease in bitumen quality due to the petroleum crisis of 1973, when moisture damage and frost became some of the most pressing pavement failure modes of the time. Hydrated lime was observed to be the most effective additive and as a consequence, it is now specified in many States and it is estimated that 10% of the asphalt concrete mixtures produced in the USA now hold hydrated lime [1]. Given its extensive use in the past 30 years in the USA, hydrated lime has been seen to be more than a moisture damage additive, hydrated lime is known to reduce chemical ageing of the bitumen. Furthermore, it generally develops the fatigue properties of the asphalt mixture which has an impact on the rutting resistance of the mixtures. In parallel, the resistance to cracking is also mentioned to be improved. As a result, State agencies estimate that hydrated lime increases the durability of asphalt mixtures for highways by 2 to 10 years that is by 20 to 50% [2]. The European experience is not yet as developed as in the USA, but the beneficial effects of hydrated lime on asphalt mixture durability have also been largely reported. As an example, the French Northern motorway company, Sanef, currently specifies hydrated lime in the wearing courses of its network, because they observed that hydrated lime modified asphalt mixture have a 20-25% longer durability. Similar observations led the Netherlands to specify hydrated lime in porous asphalt, a type of mix that now covers 70% of the highways in the country [2]. If the benefits of hydrated lime on asphalt mixtures are clearly demonstrated with a diversity of materials (aggregate, bitumen, mixture formulas) covering the 5 continents, the European experience remains somewhat lower than the one coming from the USA. Also, the description of hydrated lime in the European standards for aggregates is not totally appropriate. First, test methods such as the delta ring and ball test cannot be performed on hydrated lime, although they are required for mineral fillers.

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Hydrated lime being considered as a filler in the standards on asphalt mixtures, it is critical to resolve this situation. Then, the mixed filler classes appearing in the aggregate standards do not cover all existing products currently used. Finally, some theoretical aspects remain to be understood, and in particular the temperature-dependence of the stiffening effect of hydrated lime in bitumen and the modification of the aggregate surface after hydrated lime treatment [3]. As a result, hydrated lime in asphalt mixtures is being increasingly under research in most European countries, in particular Austria, France, the Netherlands, the United Kingdom and Switzerland and the current application and usage of hydrated lime in asphalt mixtures by most European countries is shown in Table 1 [2].

In this study, the impact of different methods of adding lime and the percentages of hydrated lime were evaluated. Three methods were used such as dry, wet and slurry. The application rate of lime is between 1% and 3% by weight of the aggregate mixture.

Table 1. Hydrated lime applications by different European countries [2]

Country	Level of Experience	Start	[Lime treated HMA] vs [total HMA] (estimate %)	% Hydrate in HMA	Form	Objective	Applications
Austria	Voluntary	2003	1	1.5 to 3.5	Pure	Stripping, rutting	AC, SMA, PA
Belgium	From compulsory to voluntary	80's	< 1	1.5	Mixed Filler	Stripping	SMA, PA (asphalt rubber)
Czech Republic	Tests	1996	< 1	1.5	Pure	Stripping, rutting	AC, PA (asphalt rubber)
Germany	Voluntary	2000	< 1	1.0 to 3.0	Pure or MF	Stripping, aging,	AC, SMA
Hungary	Tests	2009	< 1	2.0	To be defined	Stripping, rutting	AC
Ireland	Voluntary	2001	< 1	2.0	Pure	Stripping, rutting	PA
Italy	Voluntary	1998	< 1	1.0 to 2.0	MF	Stripping	SMA, PA
The Netherlands	Compulsary	Mid 1990's	7	2	MF	Stripping, aging, durability	PA
Poland	Voluntary	1998	< 1	1.0 to 3.0	MF	Stripping,	AC
Portugal	Voluntary	2000's	< 1	1.0 to 2.0	Pure	Stripping	PA (asphalt rubber)
Sweden	Voluntary / Compulsary	1998	< 1	1.0	Pure	Stripping, aging	AC
Switzerland	Preffered	2006	1	1.5	Pure	Stripping, aging, durability	PA, AC, SMA
Spain	Voluntary	2004	< 1	1.0 to 2.0	Pure	Stripping	SMA

AC: Asphalt Concrete, SMA: Stone Mastic Asphalt, PA: Porous Asphalt, CMS: Cold Mix Asphalt, BBTM: Very Thin Asphalt Layer, MF: Mixed Filler

## II. MATERIALS AND METHODS

### A. Material Properties

The aggregate used was the most commonly used for asphalt concrete pavement construction in Turkey. The selected gradation and some other properties of the aggregate determined in the laboratory are given in Figure 1 and Table 2, respectively [4]. Aggregate used in the study was obtained from Eskisehir Municipality Asphalt Department.

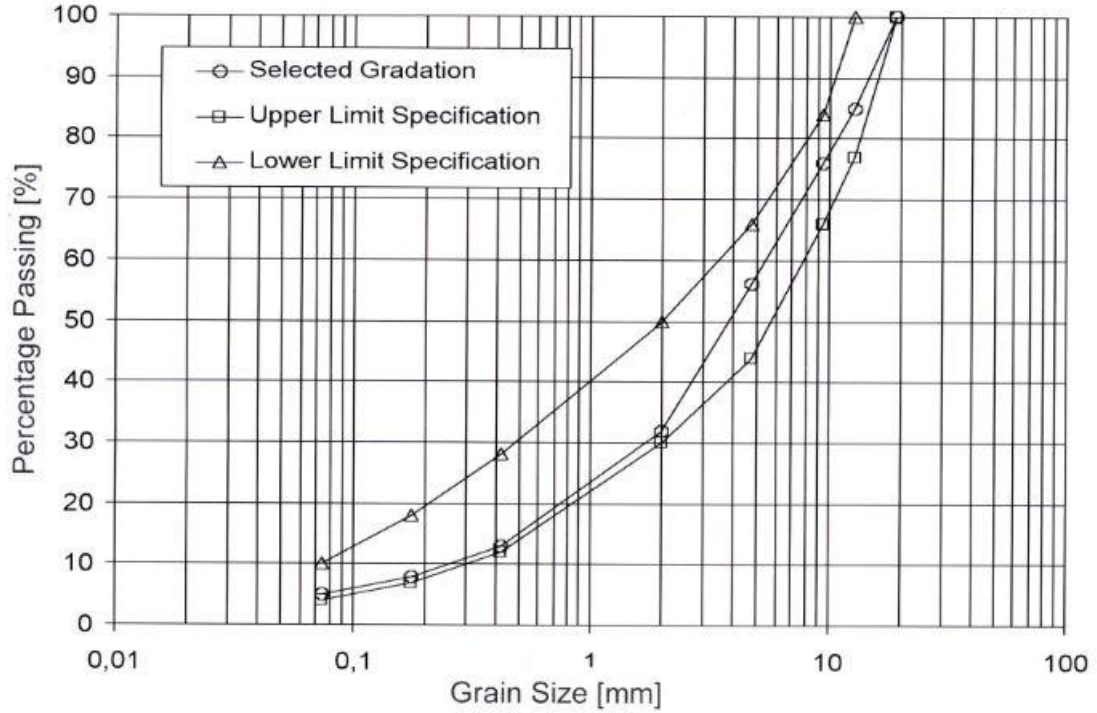


Figure 1. Grain size distributions of aggregate and upper and lower limit specifications of Turkish general directorate for highways 2013

Table 2. Properties of the aggregate

Properties	Values	Limits of Turkish general directorate for highways 2013
Los Angles Abrasion Test (%) (ASTM C131)	24	≤30
Soundness [% loss of Na <sub>2</sub> SO <sub>4</sub> ] (ASTM C88)	1.0	≤18
Flakiness Index [%] (BS 812)	11	≤25
Stripping Resistance [%] (ASTM D1664)		
B (70-100)*	55-60	B 70/100
B (100-150)#	150-155	B 100/150

B (70-100)\* : Asphalt cement penetration of 70-100  
B (100-150)# : Asphalt cement penetration of 150-200

Hydrated lime is a chemical compound with the chemical formula, Ca(OH)<sub>2</sub>. It is a colorless crystal or white powder and is obtained when calcium oxide (called lime or quicklime) is mixed or "slaked" with water. It can also be precipitated by mixing an aqueous solution of calcium chloride and an aqueous solution of sodium hydroxide. The name of the natural mineral is Portlandite. The hydrated lime used in this experiment is purchased from a local supplier in Eskisehir. The Hydrometer analysis is performed for of hydrated lime and results of the analysis is given in Figure 2. The Physical properties of the hydrated lime used in this study is given in Table 3.

Penetration-grade asphalt cement 70-100 which is widely used in Turkey. This asphalt was obtained from Eskisehir Municipality Asphalt Department and it is the preferred choice of pavement construction in Eskisehir. Table 4 gives a summary of the test results obtained from the asphalt cement in the laboratory [4].

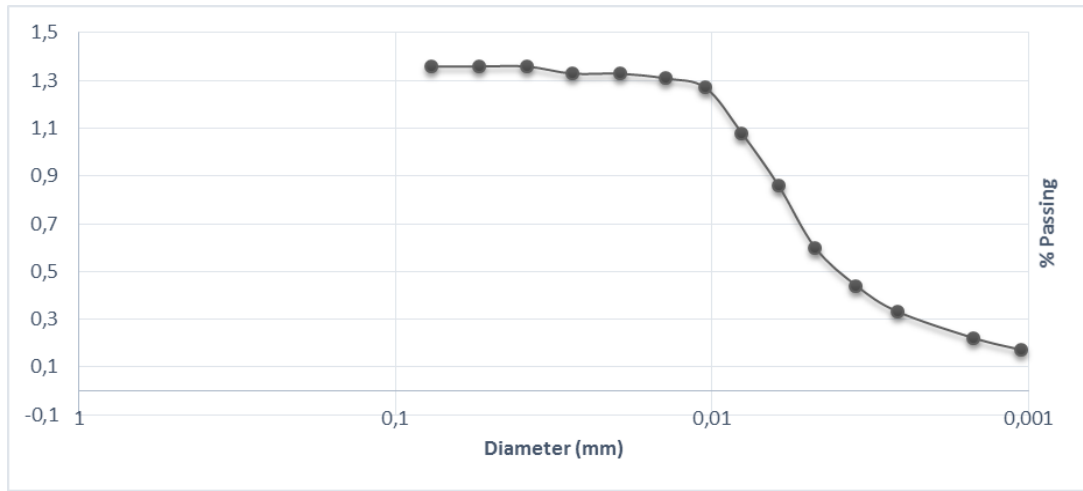


Figure 2. Hydrometer analysis of hydrated lime

Table 3. Physical properties of hydrated lime

Physical Appearance	White Powder
Specific Gravity	2.2
pH	12.4
Solubility	0.165g/100ml
Bulk Density	2210.5 kg/m <sup>3</sup>

Table 4. Properties of the bitumen

Properties	Values
Penetration 0.2 mm] at 25°C, 100g, 5s (ASTM D5)	83
Softening Point [OC], ring and ball (ASTM D36)	45
Ductility [10 mm] at 25°C (ASTM D113)	100+
Specific Gravity[%] (ASTM D70)	1.024

### B. Sample Preparation Method

As the objective is to evaluate the impact of different method of adding lime and also the percentage of hydrated lime that should be applied to mixtures. Three methods were used such as dry, wet and slurry. As a general rule, the application rate is between 1% and 3% by weight of the aggregate mixture, though in cases where severe stripping is anticipated the application amount may increase. The three methods used are described below.

In dry method, hydrated lime introduced comes in contact with aggregates and directly results in improved bond between aggregate and asphalt. The amount of hydrated lime used in this method is considered as percentage of total weight of dry aggregates. Hydrated lime could either be added prior to mixing with asphalt cement or before heating of aggregate in the oven.

In wet method, dry aggregate blends are moisturized with an addition of 3.0% water by weight of total aggregates. Dry hydrated lime is then mixed with the wet aggregates to produce evenly distributed lime-water films on the aggregate surfaces. The specimen is then placed in 180°C hot oven for 4 hours to dry out any moisture and mixed with asphalt to produce final hot mix asphalt specimens.

In slurry method, hydrated lime was first mixed with water in the ratio (by weight) of 1:3 and later that lime slurry was mixed thoroughly with the dry aggregate blend.

### III. EXPERIMENTAL STUDY

Experiments were conducted in transportation laboratory of the Civil Engineering Department at Anadolu University, in this research the optimum asphalt cement content in the regular asphalt concrete without any additive was 5%. Therefore, asphalt cement content of 5% by weight of aggregate was used for all specimens regardless of the amount of hydrated lime. This percentage (5%) was determined by using three different samples in the laboratory. The Marshall Stability test (ASTM D1559), the indirect tensile test (AASHTO T322), the moisture susceptibility test (AASHTO T283) and resilient modulus test (ASTM D7369) are performed in this study.

#### A. Marshall Stability Test

In terms of Marshall Stability, a loss of stability of lime modified asphalt mixtures is noticed by adding up to 2.5% [5]. The best Marshall Stability result was achieved from mixing asphalt with hydrated lime using wet method and at between 1% and 2% as shown in Figure 3. Therefore, Marshall Stability result of dry and slurry methods did not given. Hydrated lime amount added to the all mixtures are considered as 1% in this study.

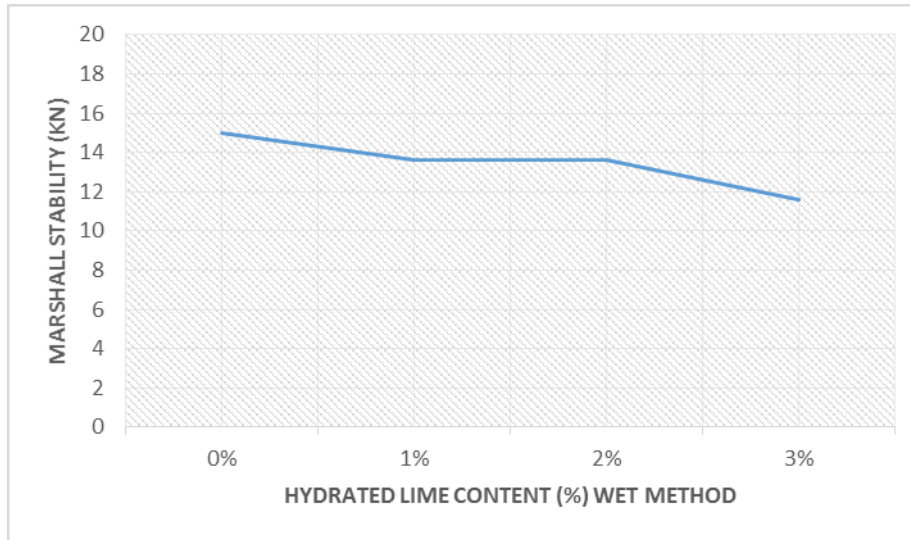


Figure 3. Marshall stability with respect to hydrated lime content

The best Marshall Stability test result was achieved from mixing asphalt with hydrated lime using the wet method among the application methods as shown in Figure 4. In the study, five percent bitumen ratio was used to compare the effects of lime added methods. However, this decreases Marshall Stability values by adding lime to the samples in all methods. This can be explained as addition of lime increases the surface area of the aggregate due to the lack of bitumen in the mixtures.

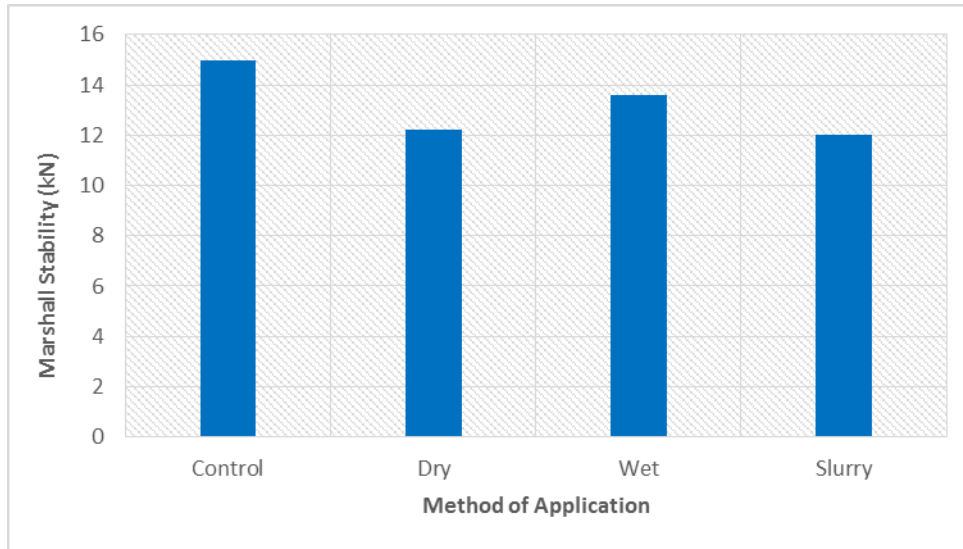


Figure 4. Marshall stability with respect to application methods

### B. Indirect Tensile Strength Test (IDT)

The effect of different application methods such as dry, wet and slurry on the tensile strength ratio of asphalt mixture seems to be more effective using wet method and gave higher tensile strength ratio than dry and slurry methods [6]. This indicates that hot mix asphalt pavements constructed with lime treated mixtures with wet method would have better long term resistance to thermal cracking than ordinary mixes. Mixtures modified with hydrated lime added in the form of slurry had higher values of indirect tensile strength as compared to other hydrated lime modified mixtures [7].

An increase in the indirect tensile strength can be noticed for mixtures modified with hydrated lime and this can be attributed to improve bond between aggregate and bitumen caused by hydrated lime. But with respect to various application methods, better indirect tensile strength was achieved from mixing asphalt with hydrated lime using the wet method as shown in Figure 5.

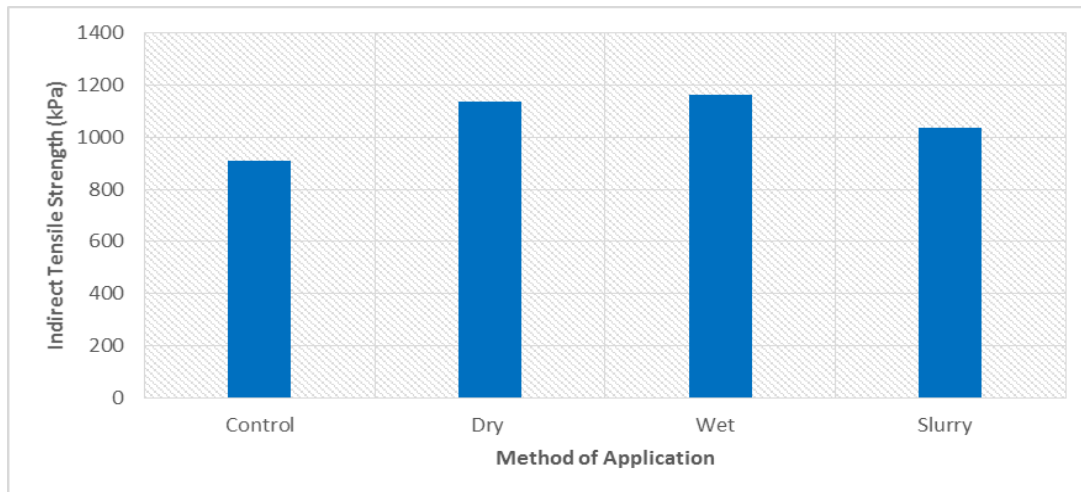


Figure 5. Indirect tensile strength with respect to application methods

### C. Moisture Susceptibility

Hydrated lime reacts chemically with the acids of the bitumen enhancing the moisture resistance of the mixtures [8]. The Tensile strength ratio values of hydrated lime modified samples are increased with the adding of hydrated lime. This indicates that the mixtures perform well with a good resistance to moisture damages. High

tensile strength value means more water-resistant that can be seen in Figure 6. The best tensile strength value was achieved from mixing asphalt with hydrated lime using wet method with respect to various application methods. Indirect tensile ratio of methods are given in Figure 7. It can be seen that all the indirect tensile ratios are greater than 70 %. This indicates that the samples have more resistance to moisture susceptibility.

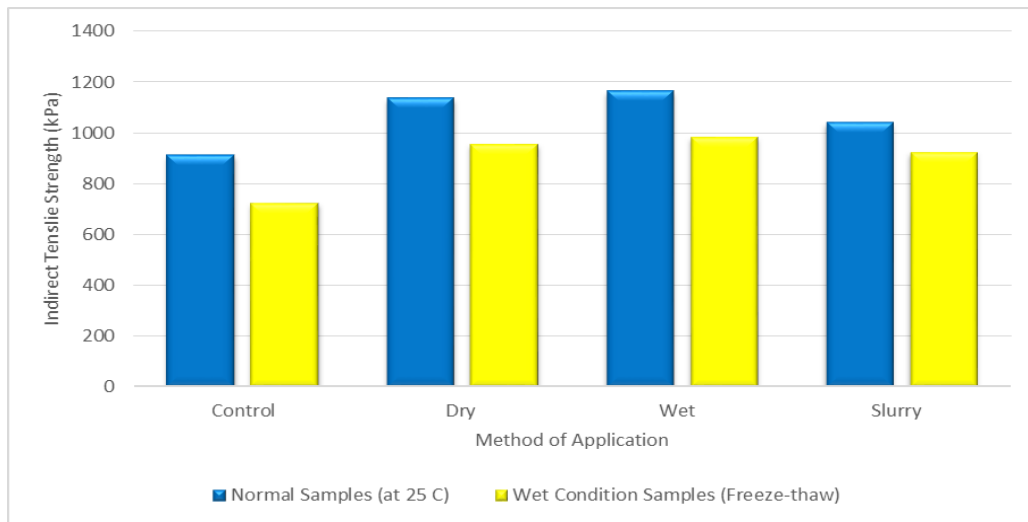


Figure 6. IDT of normal and wet conditioned samples with respect to application methods

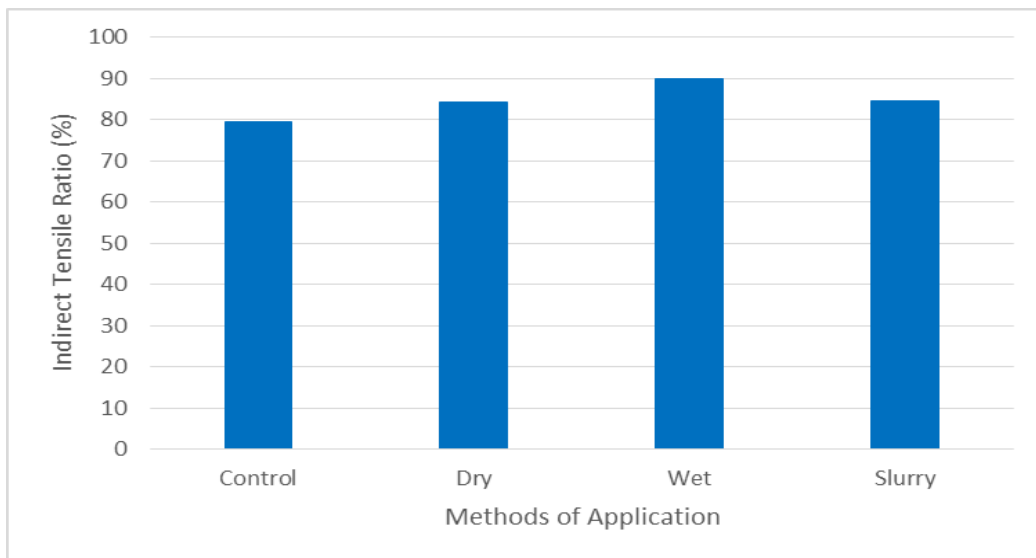


Figure 7. IDT ratios with respect to application methods

#### D. Resilient Modulus

The ability of hydrated lime to make asphalt mixtures stiffer, tougher and resistant to rutting is a reflection of its superior performance as an active mineral filler. Rutting is permanent deformation of the asphalt mixtures when the elasticity of the material is exceeded. Hydrated lime significantly improves the performance of asphalt in this respect. Unlike most mineral fillers, lime is chemically active rather than inert. It reacts with the bitumen and making it more resistant to rutting and fatigue cracking [9].

The resilient modulus of hydrated lime modified samples which is an estimation of its modulus of elasticity with rapidly applied loads. Therefore, samples with higher lasts longer under continuous loading. The values of the resilient modulus are shown in Figure 8.

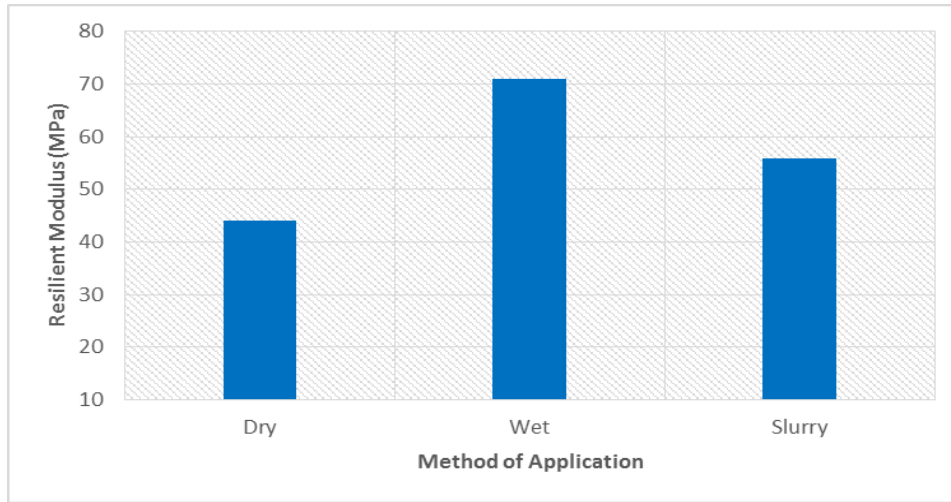


Figure 8. Resilient modulus of samples with respect to application methods

#### IV. CONCLUSIONS

On the basis of the analysis of test results obtained in the laboratory setting, the following conclusions can be drawn;

It can be concluded that, the addition of hydrated lime generally improved the fatigue properties of the asphalt mixture regardless the method of application to the mixtures. The mechanical test results were sensitive to the method of adding hydrated lime to the asphalt mixtures while the fatigue test results seemed insensitive to the method of adding hydrated lime [10].

Asphalt mixtures modified with hydrated lime using wet method showed better properties as compared to mixtures modified with hydrated lime using dry or slurry methods. This can be attributed to the best coverage of aggregate surfaces with hydrated lime in the case of wet method.

Application of hydrated lime decreased the Marshall Stability values of asphalt mixtures by a little effect but increased Indirect Tensile strength by more than 10%. Wet method gave the highest Indirect Tensile strength values with respect to method of hydrated lime application in increasing fatigue properties of asphalt. In direct tensile strength ratios show that the samples have resistance against moisture susceptibility. Therefore the addition of lime in all three methods improve the moisture susceptibility properties.

Hydrated lime content between 1% and 2% give better results for both mechanical and fatigue properties. Test results of hydrated lime modified mixtures show a resistance towards the adverse effects of water. Resilient modulus test results show that wet method has the best value. It means that samples modified with this method performs better under rapidly applied loads [10].

Overall description aids that the wet method is better than dry or slurry methods despite the little effect on Marshall and moisture susceptibility test results when comparing all the test result and seems to provide better performance for pavement.

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