# The Use of Cement Production Waste to Improve the Properties of Hot Mix Asphalt Concrete

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## ABSTRACT

Cement bypass dust (CBPD) or cement kiln dust (Ki) is a by-product (waste) generated during the production of Portland cement. Thousands of tons per day are disposed to the land fill. This big amount of waste has an adverse effect on the environment and needs a lot of money and effort for recycling or disposal. In this study, in addition to Ki, lime stone dust is used as a control filler. Laboratory tests have been conducted in order to evaluate the properties of each type of filler. The tests cover: grain size distribution, specific gravity (Gs), specific surface area (SA), pore volume (PV), mineral composition, pH and chemical composition. To study the effect of Ki on the performance of HMA mixture, several tests are conducted, including Marshall stiffness, indirect tensile strength, moisture susceptibility and creep tests. A mechanistic empirical pavement design approach in conjunction with viscosity test have been used for further analysis. The test results showed that cement kiln dust enhanced Marshall stability, mix cohesion, fatigue life, mix moisture resistance and rutting life of asphaltic mixture. It is recommended to be used in order to enhance the properties of HMA concrete and reduce the pollution and cost of pavement production.

**KEYWORDS:** Field data, Occupancy-flow relationships, Speed-flow relationships, Simulation, Calibration.

## INTRODUCTION

Cement bypass dust (CBPD) or cement kiln dust (Ki) is a by-product (waste) generated during the production of Portland cement.

As the raw materials are heated in the kiln, dust particles are produced and then carried out with the exhaust gases at the upper end of the kiln. These gases are cooled and the accompanying dust particles (i.e., Ki) are captured by efficient dust collection systems.

The composition of Ki is quite variable from source to source due to raw materials and process variations. It is primarily made up of different amounts of fine feed materials (calcined and uncalcined), fuel combustion by-products, condensed alkali and fine cement clinker compounds (Emery and MacKay, 1991). The main component of Ki is lime (CaO). It also consists of $SiO_2$ which has an adverse effect on cement quality as well as on cement production. Internationally, about 15 million tons of Ki are produced annually in the USA (EPA, 1993). Locally, in Iraq, about a half million tons per year of Ki are produced. This large amount of waste has an adverse effect on the environment and needs a lot of money and effort to be recycled or disposed of.

In order to minimize the undesirable environmental impacts of Ki, many researches have conducted research to study the beneficial use of Ki as a raw material, construction material, fertilizer or in improving soil properties. Many research studies referred to the

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advantages of using Ki to enhance the mechanical properties of asphalt concrete mixtures (Kraszewski and Emery, 1981; Emery and Seddik, 1997; Eighmy and Holtz, 2000; Konsta-Gdoutos, Shah et al., 2002; Tam and Tam, 2006; Abed and Eyada, 2009). Other researchers used Ki in agricultural land to increase the pH of the soils and reduce pH fluctuation. This can help in reducing the plant and root stress and enhancing the production (Dollhopf, 1995; McBride, Richards et al., 1997; Dudka and Miller, 1999; Pennstate, 2004). Ki is also used in soil stabilization and for the enhancement of unbound layers (bases, sub-bases and sub-grades) (Nicholson, 1977; Klemm, 1980; Miller, Bensch et al., 1980; Nicholson, 1982; Napeierala, 1983; Morgan, Novoa et al., 1984). In Iraq, very few investigations focused on the importance of using Ki for the enhancement of asphalt concrete mixtures. The main objective of this research is to investigate the feasibility of using Ki produced in Iraq as a filler in Hot Mix Asphalt (HMA) mixtures and to study the advantages of using Ki with HMA by conducting performance tests.

**Scope of the Study**

The study focuses on studying the properties of Ki and its effects on the properties of HMA, by conducting Marshall stiffness, indirect tensile strength, moisture susceptibility and creep tests. The effect of Ki on the fatigue life and rutting life of pavement is also studied using mechanistic empirical pavement design approach. The materials used in this study are collected from different sources in Iraq.

**Objectives**

The main objectives of this study are:

1- Studying the probability of using Ki as a filler in HMA.
2- Using Ki as a filler in HMA to reduce the adverse effect of Ki on the environment.
3- As a waste material, Ki is a cheap material for the production of HMA and can reduce the cost of flexible pavement production.

## MATERIALS

**Asphalt Cement**

Asphalt cement, grade (40-50), from Nasiria Refinery plant is used. The physical properties of the asphalt cement used are illustrated in Table 1.

**Table 1. Physical properties of asphalt cement used**

| Property | Symbol | ASTM designation no. | Test condition and unit | Result |
|---|---|---|---|---|
| Penetration | Pe | D-5 | 25°C,100g, 0.1 mm | 46 |
| Softening point | SP | D-36 | Ring & ball, °C | 51 |
| Ductility | D | D-113 | 25°C, 5cm/min, cm | +100 |
| Specific gravity | Gs | D-70 | 25°C | 1.028 |
| Flash point | FP | D-92 | Cleveland open cup, °C | +246 |
| Solubility | S | D-2042 | Trichloroethylene solvent, % | 99 |

**Aggregate**

Two types of aggregate are used in this study:

1- Nibaay coarse aggregate (passing sieve 3/4 inch and retained on sieve no. 4) with 100% crushed particles, brownish in colour, with quartzite mineral composition and angular faces.

2- Thmail fine aggregate (passing sieve no.4 and retained on sieve no.200) with rounded face particles, orange in color, with quartzite mineral composition.

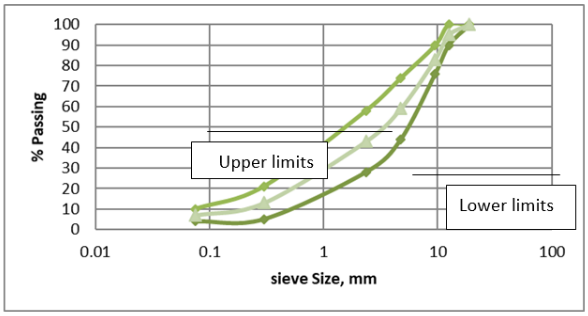



**Figure (1): Sieve analysis of aggregate**

Figure 1 shows the midline gradation of the aggregate used in the mix design. The aggregate gradation conforms with the Iraqi Standard Specifications for Roads and Bridges for 19 mm (3/4 inch) maximum size for surface course type III/A.

**Fillers**

Two different types of filler are used from two local sources in Iraq, which are:

1- Limestone powder (Li), from Karbala Limestone Factory, about 180 km to the south west of Baghdad in Iraq. It was used as a control filler.

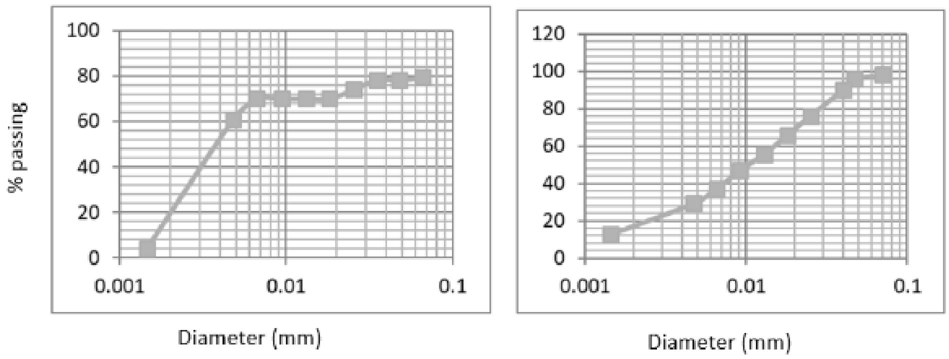
2- Cement kiln dust (Ki). It is a by-product of cement production, from Kubaisa Cement Factory, about 90 km to the north west of Ramadi city in Iraq.

The laboratory tests have been conducted in order to evaluate the properties of each type of filler, which cover grain size distribution, specific gravity (Gs), specific surface area (SA), pore volume (PV), mineral composition, pH and chemical composition.

Hydrometer analysis is conducted on each type of filler according to ASTM D-422 in order to obtain the grain size distribution as shown in Figure 2. All types of filler are passing sieve no. 200 (0.075 mm). Uniformity in the gradation of filler is also defined by the coefficient of uniformity as shown in Table 3. Specific gravity test is conducted according to ASTM D-854 using water pycnometer method.

Surface area analyzer instrument is used to determine the surface area (SA) and pore volume (PV) (i.e., volume of voids within the surface area of filler particles). Test procedure is based on Brunauer, Emmet and Teller (B.E.T.) theory.

The chemical composition test results are shown in Table 2, while the physical properties of each type of filler are shown in Table 3.




(Ki) (Li)

**Figure (2): Grain size distribution for each type of filler**

**Table 2. Chemical composition of each type of filler**

| Filler type | Percentage of oxides (%) | | | | | | |
|---|---|---|---|---|---|---|---|
| | $Sio_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | MgO | $SO_3$ | L.O.I. |
| Li | 2.36 | 0.17 | 0.27 | 52.56 | 0.92 | 1.22 | 42.19 |
| Ki | 14.82 | 5.25 | 1.98 | 49.65 | 3.35 | 6.33 | 9.77 |

**Table 3. Physical properties of each type of filler**

| Filler type | Physical property | | | | |
|---|---|---|---|---|---|
| | Gs | SA $m^2/kg$ | PV $cm^3/gm$ | pH | Cu |
| Li | 2.763 | 2.21 | 0.00530 | 7.56 | 10 |
| Ki | 2.512 | 5.61 | 0.01120 | 12.04 | 2.8 |

The mineralogical composition of each type of filler is determined using SHIMADZU X-ray diffractometer. The results are tabulated in Table 4.

**Table 4. Mineral and chemical composition of each type of filler**

| Filler type | Mineral type | Chemical composition |
|---|---|---|
| Li | Calcite | $CaCO_3$ |
| Ki | Portlandite | $Ca(OH)_2$ |

## HOT MIX ASPHALT MIXTURE TESTS AND RESULTS

To study the effect of Ki on the performance of HMA mixture, several tests were carried out.

### Marshall Test Results

Marshall mixtures are made according to ASTM D-1559 (ASTM 1995). Marshall specimens are tested to determine the resistance to plastic flow and Marshall stability strength.

Following the procedure of Marshall test, it has been found that the Optimum Asphalt Content (OAC) for Li and Ki is 4% and 4.3%, respectively.

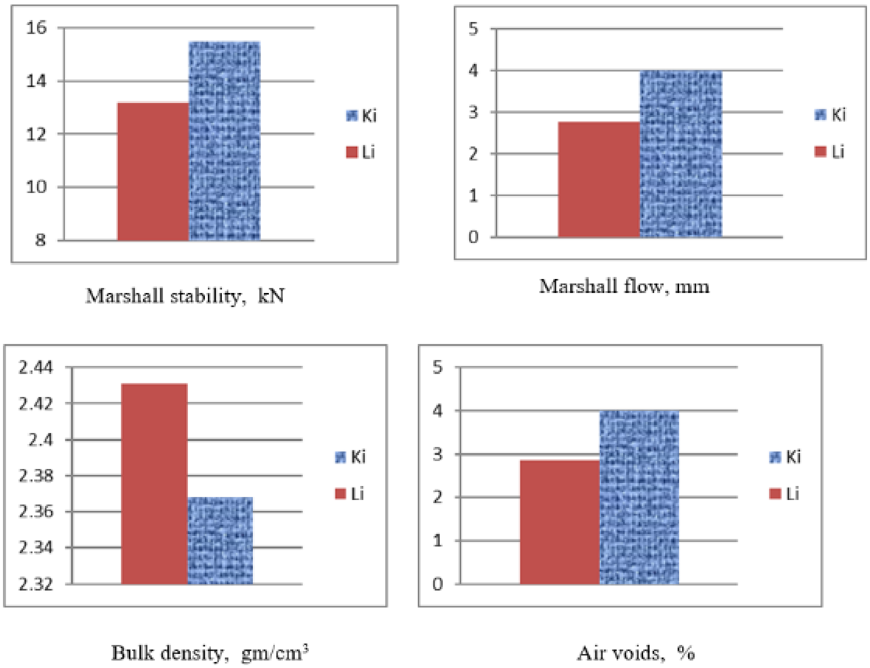



**Figure (3): Results of Marshall test for different types of filler**

The results of Marshall test are shown in Figure 3. It can be noted that Ki increased Marshall stability, air voids and Marshall flow by 17%, 38% and 37%, respectively compared with Li. At the meantime, Ki decreased the bulk density by 2.5%. The stability of mixtures containing Ki is higher than that of mixtures containing Li. It is thought that this property is associated with low Gs of Ki which increases the volume of Ki within the mix. The high volume of filler can fill the voids between the aggregate particles and increase the ability of the mix to resist the applied load by increasing the friction angle of aggregate skeleton (Abed and Eyada, 2012). Results also show that Ki increased the tendency of mixtures to flow compared to Li. It is believed that this phenomenon is associated with the high content of fine particles of single size of Ki as shown in Figure 2 (poorly graded). This has been indicated by the result of Cu which is less than 4 (Kandhal and Parker, 1998). The poorly graded skeleton (single size) of Ki can be the cause of increasing air voids of HMA due to lack of interlocking between particles. Since Gs of Ki is lower than that of Li and the air voids of mixes containing Ki are larger, it is expected that the bulk density of HMA containing Ki is lower than that of HMA containing Li.

**Indirect Tensile Strength (ITS) Test and Results**

Specimens are prepared in the same method described as in Marshall method and tested for ITS according to ASTM D-4123 (ASTM 1995). Triple specimens are tested at 25ºC and 60ºC. Figure 4 shows the test results. It can be seen that Ki increased the adhesion between the HMA particles through increasing the ITS values by 14.5% and 2% at 25ºC and 60ºC, respectively. High ITS value lowers the potential of the mix to initiate cracks and increases the fatigue life of the pavement. Figure 5 shows the results of temperature susceptibility (TS) which can be calculated using Eq. 1 (Bashoory, 1999).

$$TS = \frac{ITS\ @\ 25\quad ITS\ @\ 60}{t1 - t2} \qquad (1)$$

where:

t1= 60 °C (test temperature).

t2 = 25 °C (test temperature).

TS is an indication of the effect of variation of temperature on the stiffness and cohesion of HMA. Mixes containing Ki showed lower TS values compared to those containing Li, which means that Ki can reduce the temperature susceptibility of HMA to temperature variations between seasons and between day and night and reduce the temperature-related cracks in pavement.

**Indirect Retained Strength (IRS) (Moisture Susceptibility) Test and Results**

This method determines the stripping potential of asphalt cement from aggregate in asphalt mixtures, which is a function of the affinity between aggregate and the bitumen and its consequent ability of displacing effect of water (Khudyakova, Mashkova et al., 1990). The test was conducted according to ASTM D-4867 (ASTM, 1996). Two subsets of triple Marshall specimens were tested for ITS under conditioned and unconditioned states. The test results are shown in Figure 6. The indirect retained strength (IRS) is calculated using Eq.2 (Bashoory, 1999).

$$\%IRS = \frac{ITS\ (conditioned\ subset)}{ITS\ (unconditioned\ subset)} \times 100 \qquad (2)$$

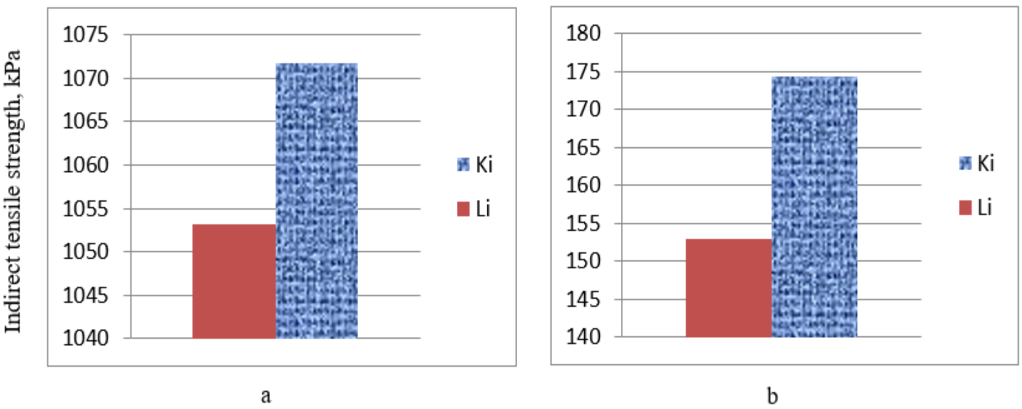



**Figure (4): The effect of filler type on ITS values at (a) 25 °C and (b) 60 °C**

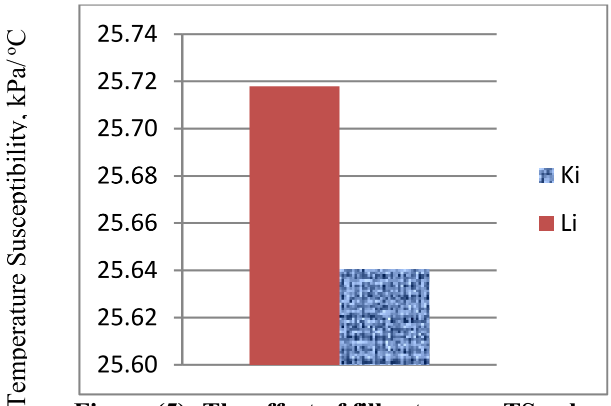



**Figure (5): The effect of filler type on TS values**

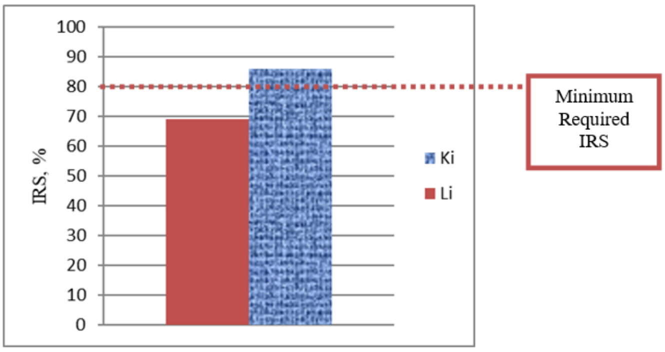



**Figure (6): The effect of filler type on IRS values**

The results show that Ki increased IRS by 24.6% compared to Li. With this result, HMA containing Ki passed the lower limit of IRS according to international standard (higher than 80%) compared to HMA containing Li. It is believed that Ki provides more adhesion between the aggregate particles and asphalt compared to Li, so that the use of Ki can increase the cohesion of the whole mix and increase the fatigue life of pavement, as can be concluded from the results of ITS at different temperatures. Meanwhile, using Ki can increase the resistance of the mix to the effect of moisture, which was obvious from the high IRS values. The ability of Ki to enhance the relationship between asphalt and aggregate is attributed to the basic property of Ki with high pH value compared to Li. This property of Ki has a positive effect on IRS of HMA mixture due to hydrophobic nature of aggregate to water with the help of Ki (Huaiz, 1990).

**Resistance to Permanent Deformation (Creep) Test and Results**

Diametrical indirect tensile creep test has been conducted to evaluate the effect of using Ki as a filler on the permanent deformation tendency of HMA mixtures at two test temperatures (25ºC and 40ºC). The results are shown in Figures 7 and 8. The tests parameters initial stiffness ($\mu_o$) at the instant of loading and permanent deformation ($\varepsilon_p$) at the end of unloading stage after 120 minutes of the test are tabulated in Table 5. These parameters are an indication of the tendency of the mixture to rutting (Kok and Kuloglu, 2007).

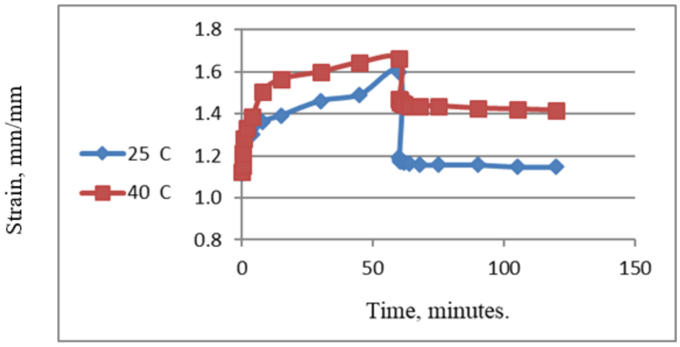



**Figure (7): The effect of temperature variation on the diametrical creep test results using Ki as a filler**

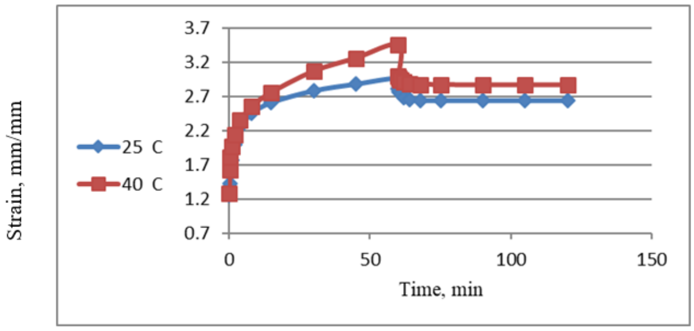



**Figure (8): The effect of temperature variation on the diametrical creep test results using Li as a filler**

**Table 5. Creep test parameters**

| Filler type | $\mu_o$ @ 25 °C kPa | $\mu_o$ @ 40 °C kPa | $\varepsilon_p$ @ 25 °C mm/mm | $\varepsilon_p$ @ 40 °C mm/mm |
|---|---|---|---|---|
| Li | 7.95 | 7.83 | 2.65 | 2.87 |
| Ki | 9.00 | 8.91 | 1.15 | 1.42 |

Table 5 illustrates that using Ki with HMA mixture increases $\mu_o$ values at the two test temperature by 13.5% compared to Li. This is an indication of the increase of stiffness of the mixture. In the same context, the increase in the stiffness of HMA has a significant effect on rutting (permanent deformation) indicator $\varepsilon_p$. HMA containing Ki lowered $\varepsilon_p$ values at different temperatures by more than 100% compared to HMA containing Li. This means that using Ki as a filler in HMA can reduce the potential of rutting in the asphaltic layer and increase the rutting life $N_f$ of pavement as indicated by Eq.3.

$$N_f = f4\,(\varepsilon_p)^{-f5} \quad (3)$$

**MECHANISTIC EMPIRICAL ANALYSIS**

In order to study the effect of using Ki on pavement performance during design life, Mechanistic-Empirical Pavement Design MEPD approach is used. Since MEPD processes cannot be made by hand, the Minnesota mechanistic-empirical design software MnPave ver. 6.3 is used (with permission) for the analysis and assessment of the effect of Ki on fatigue life FL and rutting life RL of the selected section. Table 6 shows the properties of the pavement section selected for the analysis. Traffic loading of 10 million ESAL is used.

**Table 6. The properties of pavement section**

| Layer type | Layer thickness, mm | Seasonal variation of resilient modulus, MPa | | | | |
|---|---|---|---|---|---|---|
| | | Fall | Winter | Early spring | Late spring | Summer |
| HMA | 150 | 16610 | 29690 | 21720 | 11970 | 5026 |
| Base | 300 | 36.4 | 344.7 | 13.1 | 30.6 | 37.1 |
| Subbase | 300 | 191 | 344.7 | 64.7 | 151.1 | 183.4 |
| Soil | - | 40.7 | 344.7 | 344.7 | 26.2 | 31.2 |

MnPave software calculates the modulus of elasticity of asphalt mixture |E*| under different temperatures and traffic speeds using Witzack model shown in Eq. 4 (Osman N. Celik and Eyada, 2018).

$$\text{Log } |E^*| = -1.249937 + 0.02923 .\ p_{200} - 0.001767 .\ (p_{200})^2 + 0.002841 .\ p_4 - 0.058097 .\ V_a - 0.82208 .\ [V_{beff} / (V_{beff} + V_a)] + [(3.871977 - 0.0021 .\ p_4 + 0.003958 .\ p_{38} - 0.000017 .\ (p_{38})^2 + 0.00547 .\ p_{38}) / [1 + e^{-0.603313 - 0.313351 . \log(f) - 0.393532 \log(\eta)}] \quad (4)$$

where:

$|E^*|$: dynamic modulus, $10^5$ psi
$\eta$ : binder viscosity, $10^6$ Poise
$f$ : loading frequency, Hz
$V_a$ : air void content, %
$V_{beff}$ : effective binder content, % by volume
$P_{34}$ : cumulative % retained on 19 mm sieve
$P_{38}$ : cumulative % retained on 9.5 mm sieve
$P_4$ : cumulative % retained on 4.76 mm sieve
$P_{200}$ : % passing 0.075 mm sieve.

The most important factor that affects the calculated |E*| is the viscosity of asphalt. The viscosity of asphalt binder at the temperature of interest may be determined from the ASTM viscosity-temperature relationship defined by Eq.5 (Institute, 2003).

$$\log \log \eta = A + VTS \log T_R \quad (5)$$

where:

$\eta$ = viscosity, cP
$T_R$ = temperature, degree Rankine
$A$ = regression intercept
$VTS$ = regression slope (viscosity temperature susceptibility parameter).

An experimental work has been conducted for the determination of A and VTS parameters using rotational viscosity test at 60, 90, 135 and 165°C according to ASTM D4402-15.

Pure asphalt, Ki and Li are mixed at 7% which is the same mixing percentage used in HMA mixture. The results of A-VTS parameters are shown in Table 7.

**Table 7. A-VTS parameters**

| Asphalt type | A value | VTS value |
|---|---|---|
| Ki | 13.405 | -4.5599 |
| Li | 13.129 | -4.4602 |
| Pure | 12.661 | -4.2930 |

Figures 9 and 10 illustrate the effect of Ki on FL and RL of the pavement calculated by the software.

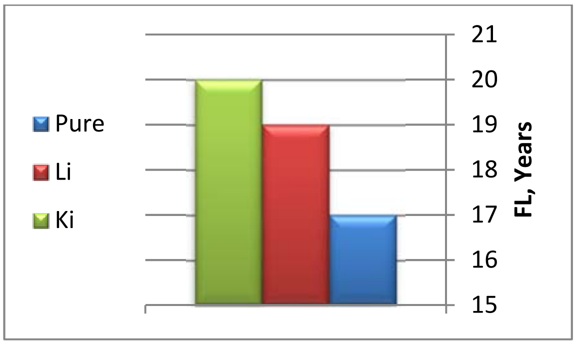



**Figure (9): Effect of Ki on FL**

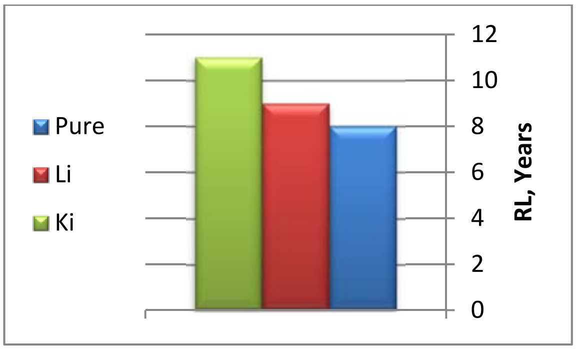



**Figure (10): Effect of Ki on RL**

The results agree with the findings of other studies, confirming that in HMA mixtures, Ki can improve pavement performance.

## CONCLUSIONS

Based on the results of the study, it can be concluded that:

1- The use of cement kiln dust Ki as a filler in HMA concrete increased Marshall stability, air voids and Marshall flow by 17%, 38% and 37%, respectively compared with HMA concrete with Li. However, the results of Marshall test are within the limits of the specifications.

2- Adding Ki to the mix has a good effect on the cohesion of mix as indicated by the results of Indirect Tensile Strength which increased by 14.5%. This can reduce the potential of the mix to cracking and can increase the fatigue life of the pavement. At the meantime, HMA containing cement kiln dust shows less susceptibility to change with temperature variation as approved by temperature susceptibility test. Less temperature susceptibility lowers the probability to low temperature-related cracks.
3- Cement kiln dust improved the relationship between the aggregate and asphalt by increasing the adhesion between them as indicated by the results of indirect retained strength test. Using Ki increased IRS by 24.6% compared to Li. Ki can be used instead of many moisture susceptibility agents as a cheap material.
4- The use of Ki can increase the stiffness of the mix by 13.5% and decrease the rutting potential of the pavement as indicated by improved creep test results. This can increase the rutting life of the pavement.
5- Using Ki as a filler in HMA can reduce the negative environmental effect of Ki.
6- As a waste material, using Ki in asphalt mixtures can reduce the cost of flexible pavements.

## RECOMMENDATION

The results show that using cement kiln dust with HMA has a positive effect on the pavement performance as well as on the environment. So, it is recommended that Ki as a cheap waste material be used as a filler in asphalt mixtures.

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