THE EFFECTS OF CEMENT AND CEMENT KILN DUST AS A FILLER ON THE MECHANICAL PROPERTIES OF COLD BITUMINOUS EMULSION MIXTURES

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ABSTRACT

The application of cold mixes is lagging behind in the research field, which is quite obvious in a developing country. Furthermore, cold mixes have more economic and environmental advantages than hot mixes. This is the principal motivation for the present research, which aims to improve the mechanical properties of cold mix asphalt. Ordinary Portland cement (OPC) and cement kiln dust (CKD) were used as filler in cold bituminous emulsion mixtures (CBEMs) to compare the obtained results with those for CBEMs with conventional limestone. Indirect Tensile Stiffness Modulus (ITSM), fatigue, and resistance to rutting tests were used in the comparison. The experimental results showed that CBEMs with CKD and OPC had comparative mechanical properties to CBEMs with limestone and hot mix asphalt of the same grading and materials. Thus, this research introduces a new cold mix with CKD or OPC, which is able to meet more than the mechanical characteristics' requirements, reduce costs, and provide environmental benefits.

Key words: cement kiln dust, cold bituminous emulsion, SEM, ITSM, fatigue, resistance to rutting

1. INTRODUCTION

The maintenance and restoration of the country's roads is the most important challenge facing the countries governments especially developing countries. Worldwide, cold mix asphalt is used in pavement maintenance such as treatment of pavement surface and reinstatement work in roads with low traffic and in sidewalks (Read and White oak, 2003).It is produced at ambient temperatures from bituminous material. Its initial cohesion is low and builds up gradually (Serfass et al., 2004).Cold mix asphalt is considered the most well-known type of CBEM. However, use of this type for structural layers is very restricted (Al Nageim et al., 2012). This may be because it takes a long time to reach its full strength after paving has been completed. It may take from two months to two years, depending on the curing times and weather conditions. Furthermore, cold mixes are sensitive to rain when they have first been laid (Chavez et al., 2007).CBEMs could be a vital alternative to Hot Mix Asphalt (HMA) if their inferior characteristics could be improved. The purpose of this paper is to investigate the effect of cement and CKD as filler on the mechanical properties of cold mix asphalt. Accordingly, it might offer a new CBEM for use not only in maintenance but also as a structural pavement layer.

2. LITERATURE REVIEW

Environment pollution from gas and other emissions from the production of hot mix asphalt has induced researchers to investigate cold mix asphalt using bitumen emulsion or cold bituminous emulsion mixtures (Thanaya, 2003). Since the 1970s, the USA and France have been widely applying the CBEM technology for road pavements, and so have a great deal of experience of its performance. In recent years, European countries have used bitumen emulsions in asphalt. CBEMs have proved to be extremely beneficial for maintenance and manufacturing of roads (Lesueur & Potti, 2004). On the other hand, there are a few countries that do not seem to want to use this process.

Many trial shave been conducted to improve the mechanical properties of cold mix asphalt, including on fatigue resistance, permanent deformation and stiffness modulus. All these properties are affected by many factors, such as: the curing time, the void content in the mixture, the grade and characteristics of the base binder, the characteristics of the aggregate, and finally the additives (Needham, 1996; Thanaya, 2003).

Several additives have been tried to modify the cold mix properties. Most of the research works recommend addition of cement as it improves the mix properties, showing highly satisfactory performances (Terrel and Wang, 1971; Schmidt et al., 1973). Head (1974) indicated that the stability of the mix was affected significantly by the addition of 1% cement; it became about three times more stable than the untreated samples. In Japan, Uemura and Nakamori (1993) recommended using OPC in emulsion mixtures. Oruc et al. (2007) statedthat adding a large amount of Portland cement to the emulsified asphalt mixture meant that this could be used as one of the pavement layers. Thanaya et al. (2009) used rapid-setting cement to improve the mechanical performance of the suggested cold mixes. The modified mix accelerated the early strength gain and improved the creep resistance and stiffness. However, using cement alone is considered costly, because it is an expensive material; in addition, it has a considerable CO_2 impact. Thus, other researchers have tried to use waste materials in improving cold mix properties. Asi and Assaad (2005) investigated the effect of fly ash on asphalt mixes in Jordan. They reported that using that waste material improved properties of the modified mixes, the resilient modulus and the dynamic creep. Al-Busaltan et al. (2012a, b) replaced the conventional mineral filler in CBEMs with waste material fly ash. The results showed high stiffness modulus and creep stiffness in comparison with the soft and hard HMA. Furthermore, the pozzolanic fly ash proved its validity when activated by the hydraulic fly ash and consequently further improvement was achieved. Al Nageim et al. (2012) used boiler fly ash residue (FA) with different percentages (0 - 5.5%) to improve the mechanical properties of CBEMs. Those results were compared with cold mix with OPC and HMA. The results indicated that using a cold mix with a high percentage of fly ash showed comparative mechanical properties to CBEMs with and without the addition of OPC or HMA. Al-Hdabi et al. (2014) compared the results obtained from traditional hot-rolled asphalt with newly developed cold-rolled asphalt containing waste bottom ash. Improvement in resistance to water sensitivity was recorded and a substantial upgrading of material. Al-Busaltan (2014) selected different waste materials to use as filler instead of OPC. The waste or by-product materials were crushed aggregate mineral filler (CMF), pulverised fuel ash (PFA), paper sludge ash (PSA),air pollution control (APC), ground granulated blast furnace slag (GGBFS), and biomass fly ash (BFA). Generally, the selected fillers increased the stiffness and porosity. However, PSA only showed significant improvement in the ITSM of the CBEMs compared with both HMA and CBEM containing OPC.

All the researchers indicated that four main benefits can be realised when using the by-product materials in CBEMs, as follows (Al Nageim et al., 2012):

- The cementitious properties of the added by-product or waste material significantly enhance the mechanical properties.
- The waste material or by-product material used as cementitious materials improves the economic benefits.
- The rapid reaction of these materials with water during the hydration process reduces the curing time, and
- The environmental gains.

3. MATERIAL AND METHODS

3.1. Materials

Crushed granite aggregates were used in this study. As shown in Figure 1, the (AC14) gradation was used according to UK specifications to meet the wearing surfaces' requirements (BS EN 13108-1).The aggregates' physical properties are given in Table 1. In this research, OPC, CKD and conventional limestone were used as a filler to prepare the CBEMs. Slow-setting cationic bitumen emulsion (C60B3) was used. The properties of bitumen binder 100-150 and bituminous emulsion are given in Table 2.A hot mix asphalt with conventional limestone filler with the same materials and gradation was used to compare the ITSM test results. Figure 2 shows the images from the scanning electron microscopy (SEM) for the different types of filler used in this study. Overall, the particles for all types are angular in shape, with a small portion of irregularly shaped particles.

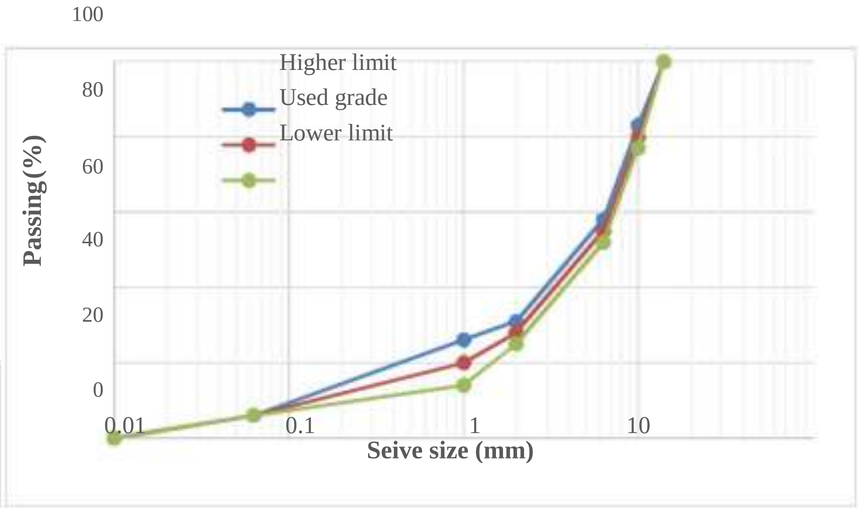

Figure 1 14C Close-graded surface course gradation

Table 1 The Physical Properties of the Aggregates

Properties	Bulk specific gravity	Apparent specific gravity	Water absorption
Coarse aggregate	2.77 gm/cm^3	2.80 gm/cm^3	0.61%
Fine aggregate	2.66 gm/cm^3	2.71 gm/cm^3	1.55 %

Table 2 The Properties of Bituminous Emulsion and Bitumen Binder

Bitumen emulsion (C60B3)		Bituminous binder 100-150	
Properties	**Value**	**Properties**	**Value**
Appearance	Black to dark brown liquid	Appearance	Black
Boiling Point ºC	101	Penetration, 25 ºC	142
Relative density at 15 ºC g/ml	1.07	Softening point ºC	43.1
Residue by distillation,%	60	Kinematic viscosity at 135°C	170
		Density at 25ºC	1.00

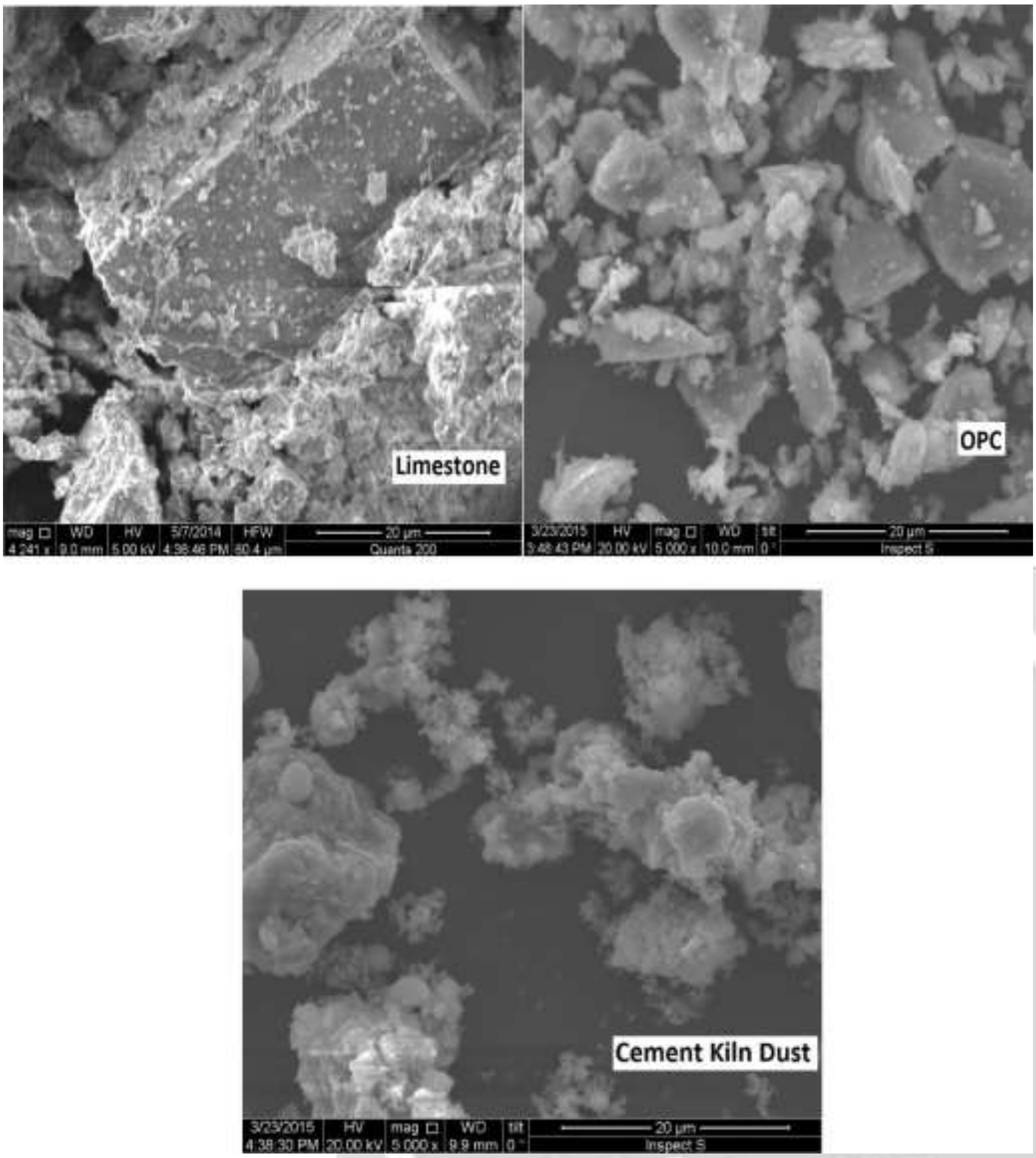

Figure 2 Scan Electron Microscopy Photos of the Selected Fillers

4. EXPERIMENTAL SETUPS

At present, there is no universally accepted cold mix design procedure. Therefore, the method adopted by the Asphalt Institute was used to prepare the CBEM samples (the cold bituminous emulsion mixture was prepared using the Marshall Method (MS-14))(Asphalt Institute, 1989). Only one change was made during the test, by using the indirect tensile strength instead of the Marshall test. Hence, the initial residual bitumen content according to the selected gradation was 10.5%, and the pre-wetting water content of the selected materials was 3%by visual judgement, as shown in Figure 3. Thus, the optimum bitumen emulsion was 13.5%.The optimum total liquid content at compaction that gave the highest density with the low porosity was 12.5%at residual bitumen content equal to6.2%, as shown in Figures 4 and 5 respectively.

Figure 4 Determination of OTLC at Compaction on **Figure 3**

Determination of Pre- CBEMs
Wetting Content

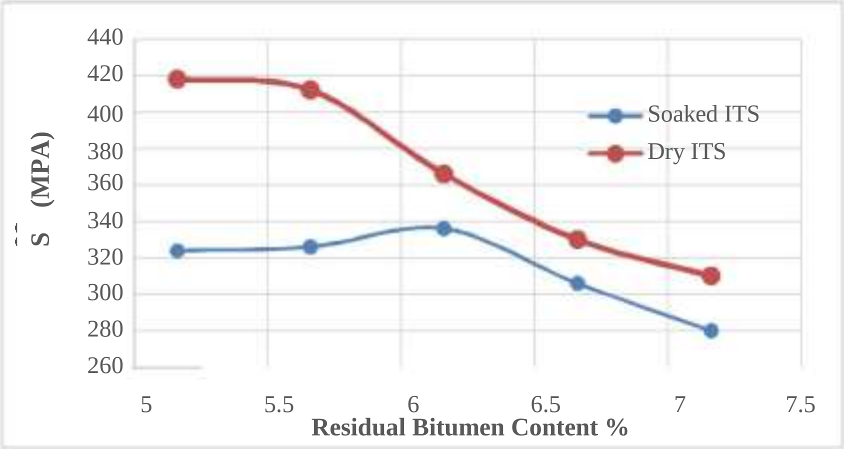

Figure 5 Determination of Optimum Residual Content

CBEM specimens were prepared using different filler types, i.e. CKD, OPC and conventional limestone mineral filler, with 6%of the total aggregate w eight. The cold mix specimens were mixed and compacted at lab temperature (20-25 °C).Two fundamental tests were used to identify the mechanical properties of the CBEMs, as follows:

- Indirect Tensile Stiffness Modulus (ITSM): The test was conducteed in accordance with BS EN 12697- 26 (British Standard Institution, 2004).
- Fatigue resistance according to BS EN 12697-24 (European Committee for Standardization, 201 2).
- Resistance to ruttin g in accordance with BS EN 12697-22 (European Committee for Standardization, 200 3).

5. TESTING

5.1. Indirect Tensile Stiffness Modulus 13363

The Indirect Tensile Stiffness Modulus (ITSM) test is a non-destructive test used mainly to evaluate the stiffness modulus of hot mixes. ITSM at 20 °C was used to evaluate the effects of the different fillers on stiffness modulus. The Cooper Research Technology HYD 25 testing apparatus was used, as shown in Figure6. The test conditions are shown in Table 3.

Figure 6 Cooper Research Technology HYD 25 Testing Apparatus

Table 3 Conditions of ITSM Test

Item	Range
Test temperature	20 ± 0.5(°C)
Specimen thickness	63 ± 3(mm)
Compaction Marshall	50 × 2
Specimen diameter	100±3 mm
Specimen temp. conditioning	4h before testing
Rise time	124 ± 4 ms
Transient peak horizontal deformation	5 µm
Loading time	3–300 s
Poisson's ratio	0.35
No. of conditioning plus	10
No. of test plus	5

5.2. Fatigue Resistance

Fatigue damage is caused by subjecting an asphalt layer to a high number of bending load repetitions. The four point bending test using Cooper technology is used to determine the fatigue life of materials under bending forces. The fatigue life is defined as the number of cycles where the stiffness is half the initial value (Pramesti et.al. 2013). The initial stiffness of the specimen will be determined automatically after the first 100 cycles of repeated loading. The specimen is a prismatic beam which is subjected to sinusoidal loading in either the controlled strain mode or stress mode. The tests were executed at a displacement-controlled temperature of 20 ˚C at a strain level designed to reach about 10^5 and 10^6 load repetitions (at 10 Hz) until the force required for the set displacement decreased to half its initial value. During testing, both graphical and tabular data were displayed on screen and test data were stored to disc in a Microsoft Excel™-compatible format, as shown in Figure 7. The test conditions are shown in Table 4.

Table 4 Four Point Test conditions

Item	Range
Force Transducer	±5kN
Specimen Transducer Range	± 1 mm
Strain	150, 200 x10^6 m/m
Frequency	10 Hz
Test Frame Dimensions mm	440 x 190 x 570
Specimen Dimensions mm	400 x 50 x 50
Test temperature (°C)	20 ± 0.5
Specimen temp. conditioning	14 day before testing
Test end value	50%

Figure 7 Cooper Four Point Apparatus.

5.3. Resistance to Rutting

To evaluate the rutting sensitivity of cold mixes with different additives, wheel-track tests are used. In this test, a rolling loaded wheel passes over a slab of material for several thousand cycles to induce material rutting under the loaded wheel. The relationship between number of cycles and corresponding rut depth is recorded (Bodinet al., 2009). At the same number of cycles, the rutting is noted, in order to make a comparative evaluation of different materials' resistance to rutting. An automatic wheel-tracking tester (HYCZ-5) is used to predict deformation in the asphaltic materials. Figure8 shows the wheel-tracking machine. The slabs were manufactured using a Cooper roller compactor, as shown in Figure 9. The slabs were 400x305x50 mm in dimension. The test conditions are shown in Table 4. The slab rut depth was measured at a temperature equal to 45 °C.

8(a) Before the test **8 (b)** During the test

Figure 8 wheel tracking machine

6. RESULTS AND DISCUSSION

6.1. Indirect Tensile Stiffness Modulus

The 24specimens for each suggested filler were tested at different ages, 2, 7, 14 and 28 days, to evaluate the effect of OPC or CKD as alternatives to the limestone mineral filler (L.S) in CBEMs. The average value for each kind was represented as shown in Figure10. It is clearly shown that using OPC instead of the limestone filler in the CBEMs increased the stiffness modulus extensively. This improvement in stiffness modulus results is due to two reasons. Firstly, the hydration process of the hydraulic reaction of OPC generated a new binder besides the residue binder. Secondly, the OPC absorbed the trapped free water. Moreover, the stiffness modulus for different CBEMs increased significantly with increases to curing time. Furthermore, the replacement of limestone with CKD in the CBEMs considerably improves the stiffness modulus, especially within the early life of the mixtures, which equals five and six times the stiffness modulus for convention allimest one after 2 and 7 days respectively. The results are comparative with the HMA 142 penetration especially for CBEMs with OPC after 2 days and CKD after 7 days. These results prove that these mixes are suitable for heavy traffic. In contrast, the stiffness modulus of the HMA was nearly constant with the curing time, which may be attributed to the hydration process.

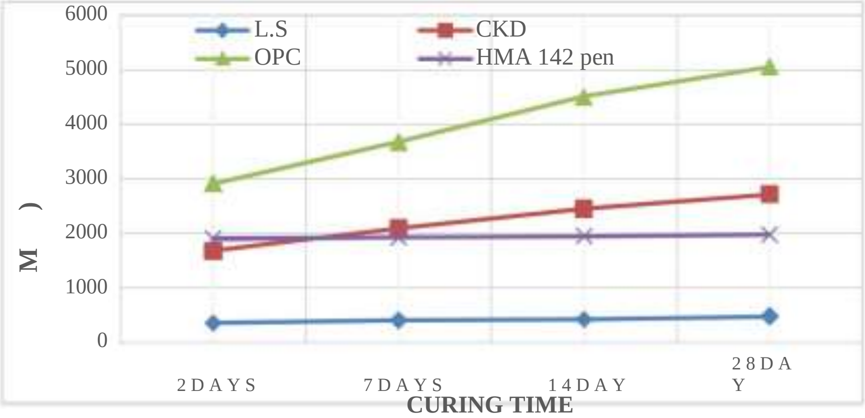

Figure 10 ITSM of HMA and CBEMs for L.S, CKD, and OPC

6.2. Fatigue Resistance

Fatigue tests were conducted according to BS EN 12697-24 at 10 Hz and at a temperature of 20 ºC. Figure 11 shows the comparison between cold mix with the three types of filler for average fatigue life corresponding to 150 and 200 micro strains respectively. The results were well-matched with the stiffness results, which indicated a preference for the OPC and CKD over the limestone.

Table 8 shows the fatigue relationships as developed for the different cold mix at strains (150 – 200 µm/m). The fatigue life relationship is defined as:

$$\log N_f = f_1 + \log \varepsilon E_1 {}_2^{-f}$$

Where N_f is number of constant strain applications until the specimen reaches half its initial stiffness, ε is the applied strain (µm/m), $f_1,$ and f_2 are the regression constants, and E_1 is the elastic modulus of the asphalt layer.

In the formula shown in table 5, 'y' is log cycle and 'x' is the product of log micro strain by inverse of modulus of elasticity ($\log \text{micro strain} \times E_1^{-1}$). The resulting coefficients of determination (R^2) and significance of the F statistics reflect a relatively high goodness-of-fit for the model and the significance of the model for use in prediction. This formula is compatible with most of the fatigue failure models which take the following form (Mathew et al., 2009):

$$N_f = f_1\, \varepsilon^{-f2} E_1^{-f3}$$

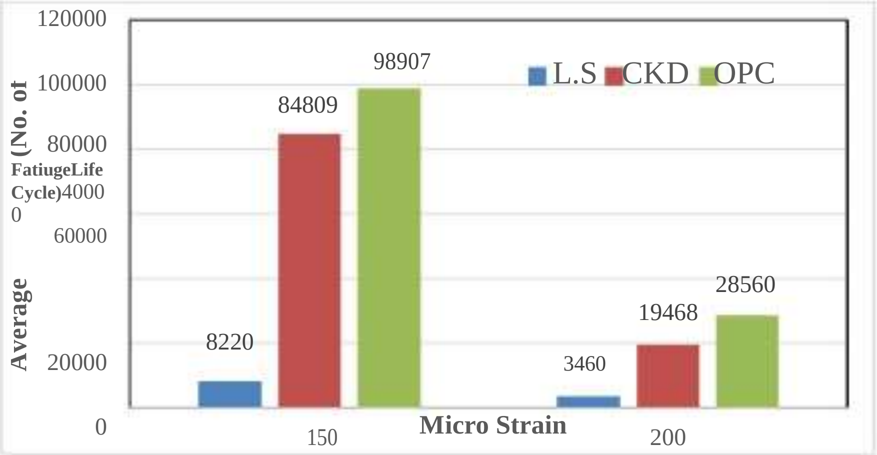

Figure 11 Fatigue Life for Different Types of Filler at 150, and 200 Micro Strain

Table 5 Fatigue Relationship for different filler types at 150 and 200 Micro Strain

Filler Type	Micro Strain	Formula	R^2	F	Sig.
Limestone	150- 200	Y = 0.246+2.567 x	0.744	8140	0.000
CKD		Y = -0.325+3.301 x	0.80	11882	0.000
OPC		Y = -0.696+4.471 x	0.86	12453	0.000

6.3. Resistance to Rutting

The rut evolution at the central position of three CBEM slabs with different fillers as a function of the number of cycles is shown in Figure 12. This figure indicates that the rut depth under the wheel path evolves quickly with time for CBEMs with conventional limestone, which equalled 13.091 mm at the end of the test. However, the same trend of curves for CBEMs with OPC or CKD evolves very slowly. The rut depths at the end of the tests for CBEMs with OPC and CKD are 0.675 and 2.0 mm respectively. These results indicate that OPC and CKD obviously improve the mechanical properties in terms of resistance to rutting. Furthermore, the difference in rut depth between OPC and CKD can be neglected comparing with rut depth of traditional limestone.

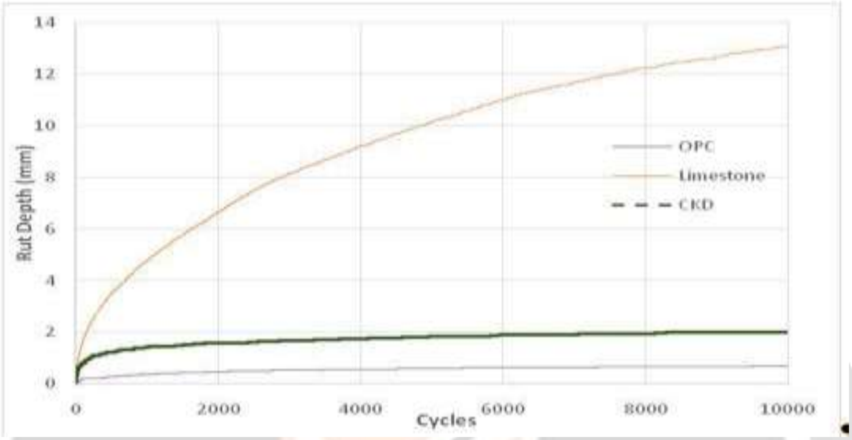

Figure 12 Slab Rut Depth Evolution for CBEMs with Different Filler Additives

7. CONCLUSION

This paper has made a comparison between different CBEMs with different fillers, conventional limestone, OPC, and CKD. The results echo the previous conclusions about OPC’s positive effect on the mechanical properties of cold mixes. CKD is a by-product material from the cement industry. Using CKD in the cold mix also improved the mechanical properties of the mix. Indirect tensile stiffness modulus and resistance to rutting were used in the comprison. The main conclusions from this study are:

- Cement kiln dust can be beneficial replacement for limestone mineral filler in CBEMs.
- New CBEMs with OPC or CKD have comparative mechanical properties to corresponding HMA made from the same materials and grading. This may be due to the shape of the OPC and CKD particles, as shown in the SEM images, which reduces the air voids and increases the level of inter locking among the particles. Furthermore, it may give more dense mixtures.
- The new CBEMs with OPC showed high strength early on in the process. Thus, it can be stated that the new paving mixtures are suitable for heavily trafficked roads in addition to low- and medium-trafficked roads.
- The new CBEMs with CKD also showed acceptable strength early on in the process. Therefore, it can be used to replace OPC or limestone in CBEMs, which will be cost effective, and environmentally friendly.
- The replacement of conventional mineral filler with OPC or CKD significantly improved the mechanical properties of CBEMs in terms of stiffness modulus and rut depth. However, more investigation is required concerning the best composition and percentage of the mix in relation to OPC and CKD or OPC and limestone.

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