



AKADÉMAI KIADÓ

Pollack Periodica •
An International Journal
for Engineering and
Information Sciences

16 (2021) 1, 25–31

DOI:

[10.1556/606.2020.00182](https://doi.org/10.1556/606.2020.00182)

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ORIGINAL RESEARCH
PAPER



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Incorporating of CKD in binder course cold asphalt emulsion mixtures

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Received: January 6, 2020 • Revised manuscript received: June 6, 2020 • Accepted: June 30, 2020

Published online: February 24, 2021

ABSTRACT

Cold asphalt emulsion mixtures are produced at ambient temperature and it have several advantages i.e., energy savings, safety and reducing CO₂ emission during manufacturing and construction, reduction of adverse environmental impact. Cement kiln dust is a fine powdery substance with appearance similar to Portland cement that is generated as a by-product material of cement manufacturing industry. The aim of this research is addition of cement kiln dust instead of Portland cement as filler in asphalt emulsion mixtures. Cement kiln dust was added with 2, 4, 6, and 8% from total weight of aggregate to improve the mechanical properties and durability of this mixture. The results were very positive and encouraging, due to the improvement of the mechanical properties and durability of the mixtures.

KEYWORDS

cold mixture, indirect tensile strength, durability, filler, waste materials

1. INTRODUCTION

Cold Asphalt Emulsion Mixtures (CAEMs) represents producing asphalt mixtures at ambient temperature using asphalt emulsion as binder. Previously, CAEMs were produced with open graded or semi-dense graded mixtures to ensure better airflow, thus improving the curing process due to the high air voids in these mixtures [1]. In line with improvement of emulsion technology and preparation techniques, currently CAEMs can be produced even with dense or gap gradation mixtures [2–5]. Suitable aggregate gradation, asphalt emulsion and pre-mixing water are required for the CAEM mix design. Zizi et al. [6] stated that the emulsion's breaking mechanism and the compatibility of the mixtures control the performance of the produced mixtures in the field. Asphalt emulsion's breaking during curing covers the total evaporation of water followed by an effective distribution of the mixture's constituents and coating of the aggregate by the asphalt emulsions. CAEMs are still limited to road pavements that accommodate low to medium traffic due to their intrinsic problems, especially insufficient early strength and long curing time required. Ibrahim and Thom [2] reported that CAEMs can be utilized in all pavement layers designed for low to medium traffic loads. However, for heavily trafficked roads, at least a 40 mm hot asphalt layer is needed to overlay the CAEM layer.

There are several materials that can be added in order to enhance the performance of these mixtures. Reactive filler, i.e., cement, is a type of filler that reacts when in contact with emulsion and/or any added water as a hydration process occurs. Meanwhile, inert filler i.e. limestone dust, will not react when mixed with emulsion [7–9].

Portland cement is the primary cementitious material in CAEM and concrete. Nowadays, many materials named as Supplementary Cementitious Materials (SCMs) may be included into concrete mixtures as a portion of cement [10–13]. SCMs are normally natural ingredients or by-products from other processes. They can be classified as cementitious and pozzolanic materials. The first have a cementitious property while the latter does not have any

cementitious properties by themselves but will react with the existence of Portland cement i.e., cementitious material.

The main benefits from incorporating SCMs in CAEM are enhancing the mechanical properties and the durability of the produced mixtures. This improvement can be attributed to the pozzolanic and cementitious properties of these materials i.e., SCM. Using of SCMs represent a promising economic benefit as the used materials are commonly industrial waste or by-products, and have ecological benefits as many of the by-product materials contain toxic elements which can be hazardous to human health when they are dumped in lakes, streams and landfills [3].

Cement Kiln Dust (CKD) one of waste materials, which is a fine substance like cement and generated at cement factories. The major compounds of CKD are silica, lime, and alumina [14]. The primary role of CKD is its cementitious property. CKD can be incorporated as a replacement for other cementitious substances i.e. as blast furnace slag cement, Portland cement and Portland pozzolan cement [15].

The aim of this study is to enhance the mechanical properties and durability of binder course CAEMs with Ordinary Portland Cement (OPC) and CKD instead of conventional mineral filler. Therefore, CKD was added in the range 0–8% by total weight of aggregate to the CAEMs containing 2% OPC to achieve this aim. Marshall Stability and Indirect Tensile Strength were used to investigate the mechanical properties of the produced mixtures while, Index of Retained Strength (IRS) was adopted to assess the water sensitivity of those mixtures.

2. MATERIALS

In this research, the materials provided are commonly used in preparation of hot asphalt mixtures especially in the middle and south of Iraq, which were aggregate, cement, asphalt emulsion.

2.1. Aggregates

The coarse aggregate, passing sieve 25 mm opening and retained on sieve No. 4, used in this work was crushed aggregate from Al-Nibaie quarry and the fine aggregate from An-Najaf City. Several tests were conducted to characterize the aggregates; the results are presented in Table 1. Aggregate gradation suitable for binder course in accordance to

Table 1. Physical properties of coarse and fine aggregate and mineral filler

Material	Property	Value
Coarse aggregate	Bulk specific gravity	2.79
	Apparent specific gravity	2.83
	Water absorption, %	0.60
Fine aggregate	Bulk specific gravity	2.68
	Apparent specific gravity	2.72
	Water absorption, %	1.6
Mineral filler	Particle specific gravity	2.71

Table 2. Selected binder course gradation

% passing by mass of aggregate		
Sieve opening size, mm Standard sieves (mm)	Specification limits [16]	Mid-limit gradation specifications
25	100	100
19	90–100	95
12.5	76–90	83
9.5	56–80	68
4.75	35–65	50
2.36	23–49	36
0.3	5–19	12
0.075	3–9	6

the general specification for roads and bridges, section R9 [16] was adopted in this research. The selected gradation with specification limits are presented in Table 2.

2.2. Asphalt emulsion

In this investigation, K3-60 Cationic emulsified asphalt is used to prepare all the specimens for CAEMs. The properties of the used asphalt emulsion are shown in Table 3.

2.3. Mineral filler

Three types of fillers were used which were, dust materials passing sieve No. 200 (0.075 mm), OPC, and CKD.

2.3.1. Ordinary Portland cement. Ordinary Portland cement is supplied from Lafarge Company in Karbala city, in this research this filler OPC used by various proportion from total weight of aggregate. Table 4 shows the physical and chemical

Table 3. Asphalt emulsion properties

Asphalt emulsion (K3-60)	
Property	Value
Residue by distillation, %	60
Relative Density at 15 °C, g/cm ³	1.05
Appearance	Black to dark brown liquid
Residual asphalt penetration, 1/10 mm	100

Table 4. OPC physical and chemical properties

Physical properties	
Passing sieve No.200	95%
Density (g/cm ³)	3.12
Specific surface area (m ² /kg)	418
Chemical testing (XRF)	
CaO	60.845%
SiO ₂	24.564%
Al ₂ O ₃	2.135%
MgO	1.625%
Na ₂ O	1.583%
Fe ₂ O ₃	1.131%
K ₂ O	0.694%

Table 5. Chemical properties of CKD

Compound	Precipitate dust
SiO ₂	12.02
Al ₂ O ₃	4.30
Fe ₂ O ₃	2.40
CaO	45.22
MgO	2.30
SO ₃	7.02
L.O.I	24.95
K ₂ O	1.007
Na ₂ O	0.628
CL	–
Total	98.21

Table 6. Gradation of CKD

Particle size, μm	% by mass
>100	5.0
<45	85.0
<30	77.3
<7	43.0
<1	12.0
<0.6	7.5
Median size, d_{50}	9.3 μm

properties (in accordance to X-Ray Florescent (XRF)) of OPC.

2.3.2. Cement kiln dust. CKD was provided from Kufa Cement Plant that represent a by produce material from producing an anti-sulfate Portland cement. The chemical properties of CKD are shown in Table 5.

CKD particle size distribution was determined in accordance to ASTM D 422-02 employing the hydrometer test. Table 6 presents the particle size distribution of the used CKD. While, Le Chatelier flask as described by ASTM C 188-95 was adopted to determine the specific gravity of CKD and it was found as 2.75. Also, CKD specific surface area was measured in accordance to ASTM C 204-05 utilizing the Blaine-air permeability apparatus available in the physical laboratory of Kufa Cement Plant, Southern Cement Company. Blaine fineness of CKD was found equal to 5,200 cm²/g.

2.4. CAEMs' design procedure

2.4.1. Asphalt Institute Design Procedure MS-14, 1989. The Asphalt Institute design procedure MS-14, which represents the common design procedure for CAEMs, was adopted in this investigation that involves the following steps [15].

2.4.2. Determination of aggregate gradation. The total mass of each CAEM sample was 1,000 g, which was collected for each sieve size in accordance to binder course gradation represented earlier in Table 2.

2.4.3. Determination of initial emulsion content and initial residual asphalt content. The asphalt Institute proposed an empirical formula to calculate the Initial Residual Asphalt Content (IRAC) that is as shown below and named as p [17].

$$P = (0.05 A + 0.1 B + 0.5 C) \cdot 0.7, \quad (1)$$

where P is the percentage of IRAC by mass of total mixture; A is the % of coarse aggregate; B is the % of fine aggregate; C is the percentages of filler. In accordance to the gradation of binder course shown in Table 2, A , B and C are 50, 44 and 6%, respectively. Then Initial Emulsion Content (IEC) can be determined using the below equation:

$$\text{IEC} = \left(\frac{P}{X} \right) \%, \quad (2)$$

where IEC is initial emulsion content; X is the residual asphalt content in the emulsion, which is 60%. Therefore, in accordance to Eqs. (1) and (2), the IRAC and IEC are 6.93% and 11.55% by mass of aggregate.

2.4.4. Determination of pre-mixing water content. The coating degree of the aggregate and asphalt emulsion is primarily controlled by the pre-mixing water content, particularly when the aggregate gradation contains a high percentage of filler. Thanaya [18] reported that the best asphalt coating on aggregate can be achieved when the mixture is not very stiff or very sloppy. Several mixtures were prepared with 3–6% premixing water content (by mass of aggregate) and with IEC = 11.55% (by mass of aggregate) to specify the lowest pre-mixing water content in accordance to visual inspection to achieve adequate coating. Therefore, 3% by mass of aggregate pre-mixing water content was selected to prepare the whole CAEMs.

2.5. Preparation of CAEMs

Specimens of CAEMs were mixed using laboratory mixing machine. The pre-wetting water content (3% by mass of aggregate) was incorporated to the aggregate and filler material and mixed for 1 minute at low speed. Then 11.55% by mass of aggregate of the asphalt emulsion was added gradually for 30 s of mixing, and the mixing was continued for another 1.5 min (total mixing time was 3 min). Then the mixture was placed in the mold with hand blows, 10 blows in the center and 15 blows in the edges. Also, standard Marshall Hammer (impact compactor) was utilized as the general compacting process with 75 blows to each face of the specimens.

In this research, three specimens of cold mixture were prepared with the binder course gradation that presented earlier in Table 2 with various percentages of filler by mass of aggregate, these mixture designations are shown in Table 7. It is worthy to state that, CKD has not been added without OPC due to its classification as pozzolanic material in accordance to its chemical properties and previous researches, therefore, there is no remarkable cementation action when be added alone.

Table 7. Mixture designation, percentages of mineral filler in the mixture

Mix number	Percentage of mineral filler % by total aggregate mass		
	Materials passing sieve 0.075 mm from fine aggregate	Cement	CKD
1	6	0	0
2	4	2	0
3	2	4	0
4	0	6	0
5	2	2	2
6	0	2	4
7	0	2	6
8	0	2	8

3. TESTING

3.1. Marshall stability test

Marshall Stability for CAEM conducted with the same Marshall Stability apparatus used for Hot Mix Asphalt (HMA) testing. After preparation and compaction, the samples are placed for 24 h. at lab temperature (30 °C) then at 40 °C in the oven for another 24 h. After extracting from the mold. Finally, the specimens are placed at lab temperature (30 °C) for 2 h at least and after that tested in Marshall Apparatus shown in Fig. 1 (left).

3.2. Indirect tensile strength test

Indirect Tensile Test (ITS) tests have been conducted according to ASTM D 4123 method [19]. The procedure of

testing specimens was adopted to indicate the tensile strength of a cylindrical specimen. It is established to apply a load with a constant rate of 50.8 mm/min diametrically in compression to generate a tension zone along the specimen's loaded diameter by taking use of two steel loading strips with (13 × 63) mm as it is shown in Fig. 1 (right). The formula of ITS can be identified as:

$$\sigma_t = \frac{2 \cdot P_{\max}}{\pi H D}, \quad (3)$$

where σ_t is the ITS in kPa; P_{\max} is the maximum applied load in kN; H is the specimen's height in m; D is the specimen's diameter in m.

The test of ITS for CAEMs specimen is conducting after compaction the sample, and cured as mentioned before for Marshall Stability (MS) test. Then cured at 25 °C temperature for 2 h at least, before conducting ITS test by Marshall Apparatus.

3.3. Index of retained strength test

Moisture damage for the whole CAEMs was evaluated by adopting a procedure that is similar to the procedure mentioned in ASTM D1075 [19]. Index of retained strength is suggested to identify the defeat of cohesion because of the action of water. In this research, IRS was determined by conducting Marshall Stability test for two sets of specimens, which were prepared and separated. The first set of samples was dry, which represent the results of MS test and cured as presented in Section 3.1. The second set of specimens were named as wet specimens, with the same conditions of the first set, except after extracting the specimens from the oven they placed in the water bath at 40 °C for three days, then extracting the specimens from water path and place them at



Fig. 1. Marshall Apparatus, Stability test (left), Indirect tensile strength test (right)

lab temperature (30 °C) for 2 h at least then Marshall Stability test was conducting.

The value of IRS can be calculated by applying equation:

$$IRS = \frac{S_2}{S_1} \times 100\%, \quad (4)$$

where IRS is the index of retained strength, %; S_1 and S_2 are the Marshall Stability of the dry and wet samples, [kN].

4. RESULTS AND DISCUSSION

4.1. Influence of OPC addition on Marshall Stability results

The stability of the mixture is a significant property for the performance of asphalt mixture in the surfacing courses i.e., surface and binder course. Layer stiffness, rutting and shoving resistance are related significantly with the stability values of mixtures. OPC was incorporated to the CAEMs as a replacement to the mineral filler 2, 4 and 6%. The results of the cold mixtures with different percentages of OPC are shown in Fig. 2.

Addition of OPC to the mixture increases its stability as it is shown in Fig. 2. Marshall Stability increased about 60, 97 and 150.7% in comparison with the control mixtures when the OPC was added by 2, 4 and 6%, respectively.

This improvement can be attributed to the generation of another binder from the hydration process of cement with the trapped water in addition to the original binder i.e., asphalt, which comply with other studies i.e., Al-Hdabi and Al Nageim, 2017 [20], Ameri and Behnood, 2012 [21], Al-Busaltan et al., 2012 [22] and Cliff et al., 2012 [23].

4.2. Effect of cement kiln dust addition on Marshall Stability results

Four percentages of CKD were added as filler to the CAEMs containing 2% OPC, which were 2, 4, 6 and 8% by a total mass of aggregate. Then Marshall Specimens were prepared and tested to indicate Marshall Stability values. MS was adopted to indicate the optimum content of CKD. The results are shown in Fig. 3.

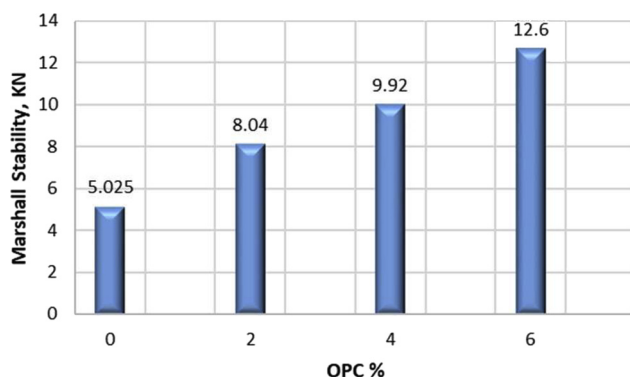


Fig. 2. Marshall Stability results for mixture with different OPC contents

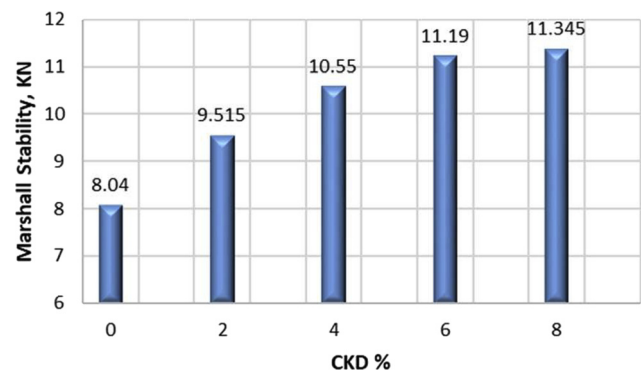


Fig. 3. Marshall Stability results for mixture with different CKD % and 2% OPC

Figure 3 shows that MS values for cold mixtures with different percentage of CKD. It is clearly shown that Marshall Stability of mixture increased significantly with increasing of CKD percentage. This increment was sharp until 6% of CKD percentage then it has been increased slightly. The percentage of increment for the mixtures with 6% CKD was more than 120% in comparison with the control mixtures (with the aggregate dust as mineral filler) and approximately 40% in comparison with the cold mixtures containing 2% OPC. Its worthy to say that these mixtures i.e. containing 2% OPC plus 6% CKD has Marshall Stability equals to those mixtures has approximately 5% OPC, which is a very promising finds by means of economic and environment. So in accordance to these results, the optimum content of CKD can be adopted to be 6%, which equals high value of Marshall Stability that can be gotten by using 5% percentage of OPC. The activity of CKD here shows the pozzolanic behavior of this material as it has very little improvement without using cementitious material i.e. OPC but enhancing the hydration process significantly when incorporated with them i.e. cementitious materials.

Figure 4 shows the relationship between mix type and ITS, whereas ITS equals to 71 kPa for control mixture (mix type 1 i.e., with 6% materials passing sieve No. 200), and increased to be about 45% and 107% for cold mixtures type 2 (containing 2% OPC) and type 7 (with 2% OPC +6%

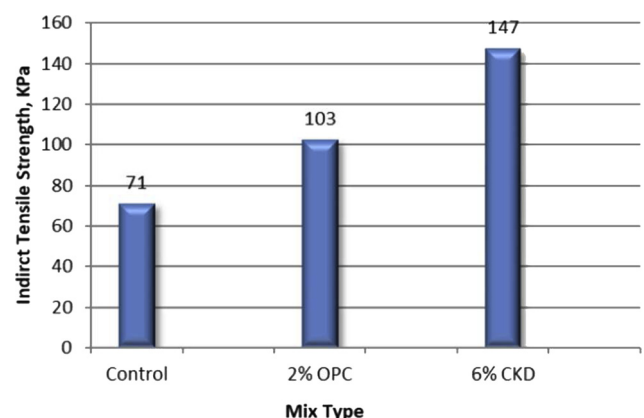


Fig. 4. Indirect tensile strength of different CAEMs samples

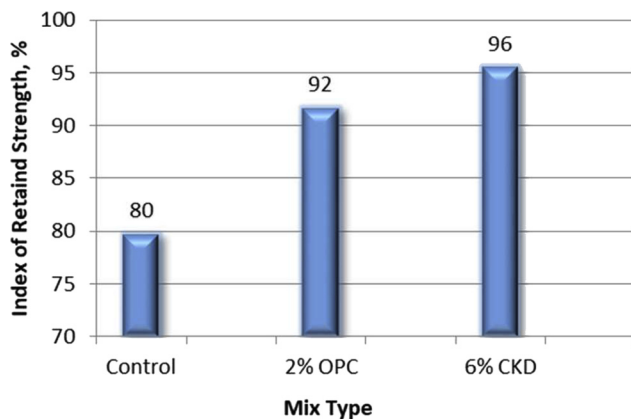


Fig. 5. Effect of OPC% and CKD% addition on index of retained strength

CKD), respectively. It is worthy to state that ITS increased significantly with the addition of optimum content of cement kiln dust (CKD) i.e., 6% to the mixtures having 2% OPC.

4.3. Effect of CKD addition on ITS

ITS is an important test that should be conducting on CAEMs to determine the tensile or splitting strength of a cylindrical specimen. The results of this test are shown in Fig. 4.

4.4. Effect of cement kiln dust addition on index of retained strength

Index of retained strength, also called water sensitivity was used to assess the moisture damage of the control and modified CAEMs. Figure 5 shows MS for these mixtures before and after exposing to water damage.

As it is shown in Fig. 5 the IRS equals to 80% for control mix i.e. mix type 1 (with 6% material passing sieve No. 200), and increased about 15% for mix type 2 (with 2% OPC and 4% materials passing sieve No. 200), and about 20% of mix type 7 (with 2% OPC plus optimum content of cement kiln dust, which is equal to 6%). Therefore, the modified mixtures i.e., type 2 and type 3 have better resistance to the moisture damage in comparison with the untreated mixtures. This performance can be attributed to the generation of another binder from the hydration process between the trapped water and cement and CKD.

5. CONCLUSIONS

This study was involved in the activation of high calcium OPC with cement kiln dust that can be included to produce a new binder course cold asphalt mixtures. This study led to the following conclusions:

1. OPC significantly increases Marshall Stability of mixture, whereas when OPC was added by 2, 4 and 6% by total mass of aggregate, MS increased by approximately

60, 97 and 150.7% in comparison with control mixture, respectively;

2. CKD was added to the cold mixtures containing 2% OPC to improve the mechanical properties of the mixture, which was added by 2, 4, 6 and 8% by total mass of aggregate, the mechanical properties of mixture improved significantly;
3. By means of MS results, the optimum content of CKD can be reported as 6% that corresponds high value of Marshall Stability after this value MS increased slightly;
4. MS for cold mixtures with optimum CKD content increased about 122% and 40% in comparison with the control mixtures and the mixtures with 2% OPC. Also, it is MS corresponds to the cold mixtures with 5% OPC, which represent a very promising finding by means of performance, economic and environmental points of view;
5. By means of indirect tensile strength results, cold mixtures prepared with optimum content of cement kiln dust increased about 107% in comparison with the control mixture;
6. In accordance to the moisture damage results, IRS for cold mixtures containing 6% CKD increased by 20% in comparison with the control mixture.

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