Influence of Curing Conditions and Filler Type on Mechanical Properties of Cold Asphalt Emulsion Mixtures

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Abstract. Strength enhancement in cold asphalt emulsion mixtures (CAEMs) is continuing and reliant on the rate at which curing proceeds. The initial life strength is low and exhibits a challenge in asphalt pavement design. The solution can be made through subjecting the specimens to accelerated laboratory curing for achieving practical conditions. Kind of mineral filler, asphalt emulsion type, curing time and temperature, and moisture content is five major factors in early age advancement of designing properties. By studying these factors, there is a requisite to build up a curing system that simulates as reasonably as actual conceivable conditions of pavement during early life. This study examines the requirement for speeded curing strength that is reasonable by concentrate distinctive curing protocols and the impact on mechanical properties of cold asphalt emulsion mixes. The experimental configuration is cautiously chosen so as to the curing conditions incorporate protocols which are trailed by various literary works and furthermore circumstances that are required for simulating different times and temperatures. The examination incorporates both cement kiln dust (CKD) and limestone mineral filler (LMF) as a filler to be utilized in the blends. One of the findings of this study is, the inclusion of (CKD) leads to strong results better than those of lime stone mineral filler mixes.

Key words: cement kiln dust, cold asphalt emulsion mixtures, curing, and mechanical properties

1. Introduction

Completely, the emulsion of asphalt cured when the water beside any volatile oils have evaporated or expelled then adhesive bond strength is built up between the aggregate and binder and aggregate. The water can be eliminated by using pressure (compacting and rolling), evaporation, and by aggregate absorption [1]. Curing, through setting and breaking stages, encourages the improvement of mechanical properties of the blend [2]. In 2009, (AEMA) clarifies that the main considerations which influence curing and breaking of asphalt emulsions incorporate: emulsifier kind and quantity, plus climate environments as hotter and elevated temperatures are positive to the setting of asphalt emulsions in order to facilitate curing [3]. Table(1) outlines key past investigations on curing regimes for (CAEMs).
Table 1. Summary of Previous Investigations of (CAEMs) Curing Regimes [4] [5].

| Reference                     | Curing Techniques                                      |
|-------------------------------|--------------------------------------------------------|
| 1    Terrel and Wang (1971).  | 1- One, three, and seven days curing at 24 C.         |
| 2    Mamlouck et al. (1981).  | 2- Three days curing in the kiln 49 C.                |
| 3    (Ruckel et al., 1982), Mauquisc, (2003), and Jenkins et al, 2004. | 1- Simulating intermediate curing of 24 hrs at 40 C°. |
| 4    Anderson and Thompson (1995). | Curing until reaching a constant weight at 38 C. |
| 5    Serfass et al., 2004.    | 14 days at 35 C° for accelerated curing.              |
| 6    UK-MCHW.                 | (Either 40 ± 2 C or 20 ± 2 ) for 28 days to simulate locally the first year of the road conditions. |
| 7    Quick and Guthrie (2011).| One year filed curing.                                |

In 2002 (Montepara and Giuliani), expressed that treated asphalt layers displayed untimely distress rapidly next to construction which unfavorably influenced pavement performance. The exploration demonstrated that cold asphalt emulsion blends showed moderate initial life strength and construction is better in dry conditions [6].

Serfass et al., (2004) submitted a few rules regarding accelerated curing that consist of: the curing technique ought to create components as near their in-place maturity state and should not fundamentally age the asphalt binder. The curing protocol ought to be as short as conceivable to avoid aging of the bitumen and the lab apparatus hardware ought not to be excessively complex. In spite of the fact that curing methodology has been standard in numerous countries, the regimes are changed and a reliable system is as of now not accessible [7].

Additives are utilized to accelerate the curing rate that gives initial strength to blend in beginning early life time. In view of cement is an expensive material in this way, it tends to be utilized the waste materials rather than cement, since they are accessible, cheap, and could be recycled, for example, cement kiln by product dust (CKD) which is collected during Portland cement production, and limestone mineral filler dust (LMF).

This work investigates, during (CAEMs) early life, the requirement for speeding up and that is sensible by evaluating and studying different curing protocols and their impact on mechanical attitude by utilizing (CKD) and (LMF) as a filler material.

2. Material Characterization

Four material types were evaluated in order to accomplish the objectives of this study. These materials are: natural sand, natural aggregate, cement kiln dust, and limestone mineral as filler type. All studied materials were isolated, graded, sieved, and mixed in order to make a job mix formula (JMF) that meet
the gradation required for coarse binder blends according to Iraqi Standard Specification for Roads and Bridges [8]. This gradation accommodated hot mix asphalt is applied since no native standard gradation for cold asphalt blend is accessible yet. The gradation of the considered materials is detailed in Figure (1). The midpoint limits gradation according to [8] requirements are utilized in setting up these blends, where the upper limit characterize the fine gradation, and the lower limit represents the coarse gradation as shown in Figure (2).

The cationic slow breaking dark brown emulsified bitumen (CSS-1) was used in this investigation because it is more prominent than other emulsion kinds and it is entirely appropriate with the adopted aggregate gradation requirements [9]. The test results demonstrated that according to (ASTM D6997) [10] the asphalt residue from distillation was (61 %), and as per [11] the softening point was (51°C).

3. Mix Design Procedure

As of now, there is no broad mechanical assembly made particularly for the production and design of cold asphalt emulsion mixtures, consequently, those for hot mix asphalt are most commonly utilized. Marshall strategy has been generally implemented for designing cold asphalt mixes in view of Asphalt Institute (Manual Series No. 14), 1989 and this specification was built up in this exploration.

Table (2) state design parameters utilized as acquired from the Asphalt Institute mix design technique for the two blends: (CKD) and (LMF) filler types. It is noticed that the total fluid content (asphalt emulsion content plus pre-wetting water content) for (CKD) blend is higher than that for (LMF) blend. This might be credited to the higher surface area for (CKD) which need and absorb extra liquids comparing to (LMF).

| Category Mix         | Initial Residual Bitumen | Initial Emulsion | Pre Wetting Water | Total fluid |
|----------------------|--------------------------|------------------|-------------------|-------------|
| (CAEMs) contains (LMF)| 6.75                     | 11               | 3                 | 14          |
| (CAEMs) contains (CKD)| 6.3                      | 10.32            | 4.5               | 14.82       |
The aggregates were washed, oven dried and patched in plastic bags with 1 kg of mass as indicated by the permitted JMF gradation in Figure (2). The pre-wetting water content was added as a thin spray to the dry aggregate mix and blended by a mechanical blender for (60 sec). A spatula was also used for (30 sec) to make sure that the aggregate was cautiously mixed and moistened to be ready for the addition of the bitumen emulsion. The essential bitumen emulsion was then added and blended for another (60 sec). To ensure consistency and homogeneity in the blend, the elements were then blended with hands using a spatula for (30 sec). These methods were blended at ambient temperature and recognized applicable for such mixtures, see [4]. Before the process of compaction, the loose mix would be discovered: if it is too wet, air ventilation may be essential until the mix is adequately loose, neither too wet nor too dry. In order to make cylindrical Marshall samples, each blend was fabricated with (65) mm height and, (101.6) mm diameter.

Curing significantly affects the mechanical properties of (CAEMs). This exploration was planned to give a substantial examination concerning the behavior of (CAEMs) considering:

- The impact of curing duration and temperature,
- The impact of filler type with various curing protocols and
- CAEMs mechanical properties differences according to curing conditioning.

Table (3) describes the strategy for the experimental study.

**Table 3.** Studied Experimental strategy.

| Stage | The temperature of curing °C | Curing Condition       | Curing Period (day) | Filler Type |
|-------|------------------------------|------------------------|---------------------|-------------|
| 1     | 25                           | Fully Sealed (FS)      | 3                   | CKD         |
|       | 40                           |                        |                     |             |
| 2     | 25                           | Partially Sealed (PS)  | 3                   | CKD         |
|       | 40                           |                        |                     |             |
| 3     | 25                           | Fully Sealed (FS)      | 3                   | LMF         |
|       | 40                           |                        |                     |             |
| 4     | 25                           | Partially Sealed (PS)  | 3                   | LMF         |
|       | 40                           |                        |                     |             |
| 5     | 25                           | Fully Sealed (FS)      | 7                   | CKD         |
|       | 40                           |                        |                     |             |
| 6     | 25                           | Partially Sealed (PS)  | 7                   | CKD         |
|       | 40                           |                        |                     |             |
| 7     | 25                           | Fully Sealed (FS)      | 7                   | LMF         |
|       | 40                           |                        |                     |             |
| 8     | 25                           | Partially Sealed (PS)  | 7                   | LMF         |
|       | 40                           |                        |                     |             |
The suggestion of partially sealed specimens conditions was presented to simulate a typical site job conditions with a coarse binder layer acting as a surface layer in order to sustain the traffic loading so that the samples will be impenetrable from bottom and sides (partially sealed). While Fully sealed specimens represent asphalt binder coarse layer that had covered by wearing surface layer. The selection of curing temperature was as the most conservative estimation to simulate the real performance of (CAEMs) on the field in addition to avoid any primary aging of the bitumen [4] and [7]. The (25 °C) represents the ambient temperature and the (40 °C) which less than asphalt residue softening point, was chosen to simulate moderate hot weather and to accelerate curing conditions.

The first attempt to accelerate the curing time of (CAEMs) was made by compacting the specimens in two layers (two lifts) in this manner enabling the moisture to escape quicker from each layer and as a result of that, diminishing the general curing time. Impact Marshall Hammer, which can be considered a fast loading rate, was used for compacting the specimens; 75 blows to each face. When compaction was finished, the samples were left in the mold for 24 hours and this was followed by curing as per the strategy as expressed in Table (2). Plate (1) displays the samples in their particular lab curing conditions.

Plate 1. Left to Right: Unsealed, Partially Sealed, and Fully Sealed Samples.

4. Testing Methods and Results

In order to describe the mechanical characteristics of CAEMs, there are several tests that could be implemented in the laboratory. In this work, Marshall Stability test and Indirect Tensile Strength test (ITS) were adopted. In the Marshall test, it is important to measure the resistance to plastic flow of cylinder-shaped samples for asphalt paving mixture. Whereas, the load is applied in a direction vertical to the cylindrical axis by means of the Marshall machine. While Indirect tensile strength test involved Marshall samples loading with uniform compressive load at 2 inches per minute rate allocating parallel to and along the perpendicular diametric level over (0.5) inch wide steel strips which have a concave curve at the interface with the samples. For these specimens, splitting fail along the vertical diameter plane will be occurring. The process of the ITS test is followed by ASTM D6931.

4.1 Impact of Curing Conditioning

Figures 3 and 4 present indirect tensile strength test results as achieved for (CAEMs) produced by cationic slow setting bitumen emulsion conditioned for 3 and 7 days at two different temperatures for
both filler types: (CKD) & (LMF). The results as seen, show that the impenetrable fully sealed (FS) samples has the lowermost strength mainly those cured at (25°C) with values of (125 KPa) and (162 KPa) respectively for both (CKD) and (LMF) mixes for three days curing. The uppermost strength values for the (FS) mixes were detected on samples cured at (40°C) with values of (304 KPa) and (249 KPa) for both (CKD) and (LMF) mixtures respectively at (7) days curing. At all curing temperatures, partially sealed (PS) specimens with (CKD) reached the highest strength. Marshall stability test results are displayed in Figures (5 & 6). The tendency detected for the test results is similar to that for (ITS). The lowermost strength values were also identified for the (FS) samples cured at (25°C) for both studied mixes. Also, at all curing temperatures, partially sealed (PS) specimens with (CKD) reached the highest strength. The added emulsion contributes to the cohesion properties of the aggregate and causes shear improvement inside the (CAEMS) using (CKD) filler as can be seen in Table (4).

![Figure 3. ITS of Specimens Cured at 25°C.](image3)

![Figure 4. ITS of Specimens Cured at 25°C & 40°C.](image4)

![Figure 5. Marshall Stability of Specimens Cured at 25°C.](image5)

![Figure 6. Marshall Stability of Specimens Cured at40°C.](image6)
4.2 Influence of Temperature on Curing

The increase of the curing temperature from (25 °C to 40 °C) accelerated water evaporation and asphalt droplets breaking which increases cohesion and friction angle of the mix. Also, moderate temperature, i.e., 40 °C, will motivate the hydration development process of the cementations filler with water. Increasing curing temperatures lead to increase in the (ITS) and Marshall stability development. This was obvious irrespective of the curing conditioning implemented. Higher rates of strength increase which led to higher maximum values. Is a result of higher curing temperatures.

During the curing process and increasing of temperature, a major phenomenon occurring is moisture loss. As presented in Figures 7 & 8, there is a substantial difference between (FS) and (PS) samples and between 3 and 7 days curing, particularly with (CKD) mixtures. However, it is obvious from the final water content differences, that in curing, moisture loss is not the only mechanism involved. Elevated temperature is undoubtedly responsible for extra strength improvement, probably by enabling aggregate- bitumen adhesion.

4.3 Influence of (CKD) and (LMF)

In all curing temperature, the addition of (CKD) increased the strength for both FS and PS conditions with a small variation comparing with (LMF) mixes. In terms of strength, the effect was somewhat less but still important. Partly, this increase is due to the elimination of water from the structure during hydration and partly due to the creation of cementitious cement.

The same behavior was conducted for (LMF) mixes in which, by mixing water with lime, certainly, one gets slaked lime. The chemical formula Ca(OH)₂ characterizes slaked lime, and it is written, in shorthand, [ CaO + H₂O → Ca(OH)₂ + Δ]. The delta or triangle sign shows heat. The extent of energy formed is an indicator of the degree lime tends to reduce water from its surroundings [12]. Because of that early heating and, as can be shown in Figures( 3 to 6), for (3) days curing at (25 °C) and fully sealed specimens, the strength of (LMF) mixtures is higher than (CKD) mixes.

4.4 Influence of Curing Time

The selection of three and seven days curing time may be attributed to the following points:

- It is essential to accelerate curing route to achieve an early sign of short term strength (less than one week).

Figure 7. Mixture Moisture Evolution at 3 days.

Figure 8. Mixture Moisture Evolution at and 7 days.
The slower time for curing regime for mixtures contains cementitious materials (e.g. (CKD) and lime) is necessary as a hydraulic binder can hydrate more quickly at elevated temperatures causing in sample cracking and untrustworthy evaluation.

As can be seen from previous figures, strength values for the (FS) samples, cured at (40°C) for (3) days were about (60 – 70 %) of those attained at (7) days and with respect to the Marshall stability marks, the ratio is around (70%).

5. Conclusions

The findings of this study are summarized as follow:
1. The temperature of curing slightly affects the strength values rate, and partially sealed specimens were cured faster than fully sealed ones.
2. Overall, the inclusion of cement kiln dust in the (FS) and (PS) cases leads to strength better results than those of lime stone mineral filler mixes. However, for the fully sealed case and at three days curing time, (LMF) mixture is the best choice this means avoiding the effects of damage during early life.
3. In order to accelerate curing time for (CAEMs) so as to estimate its early life mechanical properties, the following regimes are adopted:
   A. For mixes containing CKD mineral filler: curing of the partially sealed specimen at 40 °C for 7 days.
   B. For mixes containing (LMF) : curing of the partially sealed specimen at 40 °C for 7 days.
4. Strengths results at 3 days are nearly (60-70%) of those at 7 days, showing the hazard of damage due to early trafficking.

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