Evaluating the rutting resistance for half warm bituminous emulsion mixtures comprising ordinary portland cement and polymer

Muna AL-Kafaji¹, Shakir Al-Busaltan² and Hussein A. Ewadh³

¹ External lecturer, Dept. of Civil Eng., University of Kerbala, Iraq,
² Assist prof. Dr., Dept. of Civil Eng., University of Kerbala,
³ Prof. Dr., Dept. of Civil Engineering, University of Babylon,

Email: munafadil@yahoo.com

Abstract: Comparison of Cold Mix Asphalt (CMA) technology to traditional Hot Mix Asphalt (HMA) technology, reveals that the first has several advantages in terms of economic, eco-friendly, safety and sustainability. A promising development of CMA technology is Cold Bituminous Emulsion Mixtures (CBEMs). Unfortunately, some characteristics of this technology are still in development need; namely high porosity, long curing time and low early strength. Half Warm Bitumen Emulsion Mixture (HWBEM) was introduced in previous attempt, as a treated CBEMs with optimum heating temperature being less than 100 ºC. This work focuses on treating the CBEMs with low heat energy technique (i.e., microwave heating), plus two types of admixtures; Ordinary Portland Cement (OPC) and acrylic (AR) polymer. The effect of low energy heating (i.e., microwave heating) on developed CBEMs characteristics is tested. Acrylic (AR) polymer was utilized in percentages of 1.25, 2.5, 3.75 and 5% of the residual bitumen. The developed mixtures of HWBEM is tested statically by Marshall and dynamically by Wheel track parameters. The results reveal that the HWBEM with OPC and 1.25% AR, showed better deformation resistance roundly 81 times with vital development in its mechanical and volumetric properties comparable to traditional HMA. Therefore, low energy heating and polymer treatment sustain the new promising paving technology called HWBEM.

Keyword
Bitumen emulsion; CBEM; HWBEM, paving technology; sustainablilty

1. Introduction
Currently, construction of the pavement with sustainable technology has become very interesting for most of the researchers because of extreme cost of construction and the threat to the environment posed by using conventional technology which is (HMA). Therefore, using sustainable technology such as Cold Mix asphalt (CMA) especially the Cold Bitumen Emulsion Mixtures (CBEMs) as one type of this technology was solution of these problems. CBEMs technology are made, blended, and compacted at normal temperature. Unfortunately, this technology has inferior mechanical properties compared to conventional HMA such as reduced mechanical properties of early life and high porosity. Essentially, these deficiencies prevented the use of this technology as a substitute to conventional HMA. Thus, several methods were utilized to develop this technology such as filler types [1-5], advance polymers [6, 7], and compaction energy [2, 8], heating technique by microwave [9, 10]. These methods of modification demonstrate slight advance in volumetric properties although the modification for other properties.
Therefore, the researchers try to use other techniques (i.e. heating technique) to develop the porosity of CBEM compared to conventional HMA, without any negative effect on the obtained characteristics. Al-Busaltan et al. [10] reported that heating procedure for CBEMs with temperature up to 100°C by microwave energy has the main effect on engineering properties of mixture such as improving the resistance of permanent deformation, decrease in porosity to suitable level, the ageing and water damage compared to conventional HMA, and advancing the fatigue characteristics for control CBEMs. Also, AL-HDABI [9] used heating procedure by microwave energy to demonstrate its effect on cold rolled mixtures. He stated that heating procedure pre-compaction at 69°C has significant effect in reducing the porosity, reducing sensitivity of mixture to water damage, and improving mixture properties at early life.

The main aim of this research work is to investigate the significance of low energy post-heating technique (microwave heating) in developing asphalt mixture having acceptable permanent deformation resistance. The proposed asphalt mixture is modified by polymer first to upgrade its properties, then further development will expect due to post-heating technique.

2. Materials and Methods

2.1 Materials

The aggregates utilized in this study were prepared from local quarries in Karbala. The aggregates gradation was according to Iraqi specifications; General Specification for Roads and Bridges (GSRB), R9 [11], as shown in Figure 1. Also, Ordinary Portland Cement (OPC) was used as filler material.

Cement asphalt was prepared from Al-Neisseria factory with gradation (40-50); its properties were achieved to limits of the GSRB. The bitumen emulsion with commercial name “POLYCOAT” was prepared by Henkel Company; its properties are given in table 1. Table 2 shows the properties of the acrylic (AR) polymer, which is prepared by Conmix Company.

![Figure 1. Particle size distribution of the used gradation](image)

2.2 Experimental plan

The experimental work included the preparation of four types of test specimens as follows:

- Types one and two: HMA and CBEM specimens, included one type of filler (OPC) with gradation similar to HWBEM for compression purposes.
- Type three: HWBEM specimens comprised one type of filler (OPC) with (7%) for comparison purposes.
- Type four: HWBEM, which has OPC as fillers, in addition to an acrylic (AR) polymer, to evaluate the effect of the polymer on the rutting resistance. Four percentages of acrylic (AR) polymer were utilized from 1.25 to 5% with incremental 1.25% from weight of bitumen residue.

The mixtures matrix is as shown in table 3.
Table 1. Properties of bitumen emulsion

| Property                          | Specification | Limits                        | Results                                        |
|----------------------------------|---------------|-------------------------------|------------------------------------------------|
| Emulsion type                    | D2397[12]     | Rapid, medium and slow-setting| Medium-setting (CMS)                           |
| Color appearance                 |               |                               | Dark brown liquid                              |
| Residue by Evaporation, %        | D6934[13]     | Min. 57                       | 58                                             |
| Specific gravity, gm/cm³         | D70[14]       |                               | 1.05                                           |
| Penetration, mm                  | D5[15]        | 100-250                       | 230 uniformly and thoroughly coated            |
| Aggregate Coating                | D6998[16]     |                               |                                                |

Table 2. Properties of the acrylic polymer

| Property                  | Test Method           | Standard limits | Results of Test |
|---------------------------|-----------------------|------------------|-----------------|
| Component                 | -                     | Single           | Single          |
| Form                      | -                     | Liquid           | Liquid          |
| Colour                    | -                     | Milky white      | Milky white     |
| Specific gravity          | ASTM D1475 [17]       | 1.02 kg/Lr +/-0.05 | 1.06 kg/Lr     |
| Viscosity 25°C            | -                     | 100 ± 50 cps     | 125 cps         |
| Percent of the solid      | -                     | 49.0 ±1.0%       | 49              |

Table 3. The designation names abbreviations for bitumen mixtures

| No. | Mix Symbols | Mix details                                                   |
|-----|-------------|---------------------------------------------------------------|
| 1.  | HMA-OPC     | Hot Mix Asphalt including Ordinary Portland Cement            |
| 2.  | CBEMs – OPC | Cold Bitumen Emulsion Mixtures Including Ordinary Portland Cement |
| 3.  | HWBEM – OPC | Half Warm Bitumen Emulsion Mixture Including Ordinary Portland Cement |
| 4.  | HWBEM -OPC- X%AR | Half Warm Bitumen Emulsion Mixture Including Ordinary Portland Cement and X (of bitumen residue) Acrylic polymer. X is either 1.25, 2.5, 3.75, or 5 %. |

2.3 Specimens preparation and Conditioning

In this work, the specimens of CBEM and HWBEM were prepared according to the design method that was recommended by MS-14 [18].

The preparation process of specimens including some phases are:

- Principally, coating test was done to measure the compatibility between the aggregate particles and emulsion binder, which is very sensible to pre-mixing water content, especially, when the mixture includes a high percentage of the fine aggregate.
- Pre-mixing water content was achieved visually as described in MS-14 [18], via trying some attempts of pre-mixing water contents. As a result of the properties, the utilized materials in this work, pre-mixing water contents was equal to 3.5% for CBEM-OPC.
- Then, the gained pre-mixing water contents with several bitumen emulsion content were tested to determine the optimum bitumen emulsion content. This percent gives best volumetric
properties and maximum Marshall Stability. However, the optimum bitumen emulsion content was 12% for CBEM-OPC; thus, optimum total liquid content was 15.5%. The formulation and compaction were done at laboratory temperature (20 – 25°C).

- Blending machine was used for blending the aggregate particles, filler and pre-mixing water for 1 minute. Then, the bitumen emulsion was added gradually in 1 minute of blending. Marshall Hammer was used to simulate heavy compaction by providing 75 blows on each side of the specimen. Vibratory compaction for 3 minutes was used for wheel track specimens. The preparation and compaction were done at lab temperature (20 – 25°C).

Preparation process of HWBEM included some additional steps, which are as follows:

- After the mixing process, loose CBEM, was conditioned in microwave for different times; i.e., 1.5, 3, 4.5, 6, and 7.5 mins to select optimum time that shows the best volumetric and mechanical properties. Then, after heating, loose mixture melded and compacted by Marshall Hammer in 75 blows for each side. Wherever, same curing method used for CBEM, was based here.
- Temperatures of the conditioned mixes were recorded after the heating process. Figure (2) shows the relationship between heating time by microwave and the temperatures of mixture. Also, it demonstrates that treatment temperature is under 100 °C, therefore, the new technology can be called Half Warm Bitumen Emulsion Mixture (HWBEM).

![Figure 2. Heating time vs. temperature in microwave](image)

2.4 Test Methods and Conditions
2.4.1 Marshall Test. This test addresses the resistance of plastic deformation of bituminous mixture. Directed load is applied perpendicularly to the cylindrical axis according to ASTM D6927 [19]. CBEMs and HWBEM specimens were cured in mold for 24 hrs, then for an additional 24 hrs. at 40 °C in oven, before test was performed to prevent the deformation of specimens. It is worth mentioning that MS-14 recommended test temperature for CBEMs at 25°C, while in this work 60 °C was utilized to represent the high temperature of local environment.
2.4.2 Wheel Track Test (WTT). This test is used for simulating the rutting resistance of bituminous mixture. Slab specimens of (300x165x50 mm) were prepared as recommended by the BS EN 12697-22. The testing conditions are shown in table 6. Generally, this method is specified for HMA, but it can be adopted for CBEMs with slight difference in curing system. For this purpose full curing system utilized as second stage, full curing time can be obtained by 14 day @40°C, as recommended by Thanaya [5].

3. Results and Discussion
3.1 Volumetric Properties
The results demonstrate that increasing content of AR polymer leads to a decrease in the density as can be seen in figure 3, such decrease back to increase the water in total mix (the water form continuous phase of AR polymer). If no heat is used, such water will leave the mix later on, result in decrease in density. Correspondingly, the above behavior is reflected on the properties of the air void, as shown in figure 4.

![Figure 3. Density results of different mixtures type](image1)

![Figure 4. Air Void results of different mixtures](image2)

Also, the V.M.A of modified and unmodified HBWEM demonstrate a continuing increase as can be seen in figure 5, which might be due to continuous increase in air void content. Whereas, the increase in AR polymer leads to the continuous decrease in V.F.B, as can be seen in figure 6. Such reduction is back to the increase of the AR polymer at the expense of bitumen.
3.2 **Marshall Test Results**
The results demonstrate that AR polymer could increase Marshall Stability. HWBEMs including 1.25 % AR polymer demonstrated advanced properties than a non-polymer mix, but further polymer dosage could affect stability, as can be seen in Figure 7. This increment in Marshall Stability back to the cross-linking properties of the polymer, where primary and secondary binding properties is developed.

Also, flow results of HWBEM – OPC initially increase with the increase in AR polymer, as a result of polymer extra elastic properties. Then it decreased as an adjustment of cross linking, after that it increased because of an extra increase of elastic material, as can be seen in figure 8.

3.3 **Wheel Track Test**
The results demonstrated that the optimum value of the rutting resistance for modified HWBEM with OPC by AR polymer at 1.25%, as can be seen in Figure 9. Dynamic stability of HWBEM with OPC and 1.25% AR is higher than each of conventional HMA and HWBEM and control HWBEM by about 2233%, 1233 and 300 %, as demonstrated in figure 10. These results are due to the initiation of both primary and secondary binding.
Figure 7. Marshall Stability results for different mixtures type

Figure 8. Marshall Flow results for different mixtures type

Figure 9. Rutting versus Cycle Number for HWBEM-OPC-AR
4. Conclusions
Within the scope of this research work and from the obtained results, the following can be concluded:

1. HWBEM comprising OPC appeared a successful alternative when compared with conventional paving mixtures, it has volume and mechanical properties superior than HMA.
2. HWBEM comprising OPC-1.25% AR has volumetric, Marshall stability (MS), and rutting resistance properties superior to HMA, while Marshall flow (MF) is an exception.
3. Dynamic stability of HWBEM comprising OPC-1.25% AR is higher than that of control HWBEM.
4. High dosage of AR limits the gain in permanent deformation resistance.

Acknowledgments
The authors wish to thank the Department of Civil Engineering, College of Engineering at the University of Kerbala and Department of Direct Implementation at Karbala Government Office for their help and support in this research work.

References
[1] Al-Busaltan S, et al. 2012 Mechanical properties of an upgrading cold-mix asphalt using waste materials. Journal of materials in civil engineering 24(12): pp 1484-1491
[2] Thanaya I N A 2007 Evaluating and improving the performance of cold asphalt emulsion mixes. Civil Engineering Dimension 9(2): pp 64-69
[3] Al Nageim, H., et al., 2012 A comparative study for improving the mechanical properties of cold bituminous emulsion mixtures with cement and waste materials. Construction and Building Materials 36: pp 743-748
[4] Thanaya I 2003 Improving the performance of cold bituminous emulsion mixtures (CBEMs): incorporating waste. PhD thesis, University of Leeds, UK
[5] Ahmed S B 2017 Enhancement of Cold Mix Asphalt Using Local Waste Materaials for Binder Layer Pavemant. MSc thesis, University of Kerbala, Iraq
[6] Chávez-Valencia L E et al 2007 Improving the compressive strengths of cold-mix asphalt using asphalt emulsion modified by polyvinyl acetate. Construction and Building Materials 21(3): pp 583-589
[7] W Warid M Naquuddin M, Hainin Mohd Rosli, Haryati Yaacob Md, Aziz Maniruzzaman A, Idham Mohd Khairul, Abdul Noor Azah and Raman Rosmawati Mamat 2015 Effect of
Styrene-Butadiene on rheological properties of Asphalt emulsion. Jurnal Teknologi (Sciences & Engineering) 77:23 pp 1–5

[8] Ibrahim H E-S M 1998 Assessment and design of emulsion-aggregate mixtures for use in pavements. PhD thesis, University of Nottingham, UK

[9] AL-HDABI A 2014 High strength cold rolled asphalt surface course mixtures. PhD thesis, Liverpool John Moores University, UK

[10] Al-Busaltan S F S 2012 Development of new cold bituminous mixtures for road and highway pavements, in School of Built Environment. PhD thesis Liverpool John Moores University, UK

[11] GSRB, 2003 General Specification for Roads and Bridges, Section, Hot-Mix Asphalt Concrete Pavement R9. State Comission of Roads and Bridge, Iraq

[12] ASTM, D2397, 2013 Standard Specification for Cationic Emulsified Asphalt. American Society for Testing Material, West Conshohocken, PA, United States

[13] ASTM, D6934, 2008 Standard Test Method for Residue by Evaporation of Emulsified Asphalt, American Society for Testing Material, West Conshohocken, PA, United States

[14] ASTM, D70, 2009 Standard Test Method for Density of Semi-Solid Bituminous Materials (Pycnometer Method), American Society for Testing Material, West Conshohocken, PA, United States

[15] ASTM, D5, 2015 Standard Test Method for Penetration of Bituminous Materials. American Society for Testing Material, West Conshohocken, PA, United States

[16] ASTM, D6998, 2011 Standard Practice for Evaluating Aggregate Coating using Emulsified Asphalts, American Society for Testing Material, West Conshohocken, PA, United States

[17] ASTM, D1475, 2013 Standard Test Method For Density of Liquid Coatings, Inks, and Related Products, American Society for Testing Material, West Conshohocken, PA, United States

[18] Asphalt Institute, Asphalt Cold Mix Manual, manual series No.14 (MS-14). 3rd ed. 1989, Maryland, USA

[19] ASTM, D6927, 2015 Standard Test Method for Marshall Stability and Flow of Asphalt Mixtures. American Society for Testing Material, West Conshohocken, PA, United States