Investigation of Binder Course Cold Asphalt Emulsion Mixture Properties Containing Cement and GGBS

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Abstract. Cold bitumen Emulsion Mixture (CBEM) is a mixing of aggregate with emulsion of asphalt that is blended at room temperature. It has many environmental and economic advantages. But, the lower performance and high water sensitivity of CBEMs at early stages needs more investigation. This is the principal purpose of this research, which aims to use CBEMs as a structural binder layer after improving the mechanical properties by adding Ground-Granulated Blast-furnace Slag (GGBS). In this research the mineral filler is only materials passing (sieve No.200) replaced with (GGBS) by percentages (2, 4, 6, and 8) by total weight of aggregate with 2% of ordinary Portland cement (OPC) to enhance the mechanical properties of CBEMs and then the optimum content of GGBS was chosen based on Indirect Tensile Strength test (ITS) results. The optimum content of (GGBS) was 6% which improved significantly ITS value to more than (149%) in comparison with the control mixtures in which the mineral filler is only materials passing sieve No.200.(at age 28days). As for the other laboratory tests that represented of Marshall Stability (M.S) test and index of retained strength (IRS) test, the experimental results were very encouraging, the value of M.S of mixtures with optimum content of GGBS increased about 220% and IRS was increased about 335% in comparison with the control mixtures. Accordingly, this search has exhibited much enhanced CBEMs with GGBS in addition to the economic and ecological advantages.

Key words: cold mixture, GGBS, indirect tensile strength, durability, filler, waste materials.

1. Introduction

There are several methods to achieve the required workability of bitumen at low temperatures, i.e. decreasing bitumen viscosity; namely by using: cut back bitumen produced from mixing the bitumen with flux oil, foamed bitumen produced from foaming process of the hot bitumen with cold water, and bitumen emulsion produced from emulsification of bitumen emulsion with water [1]. This research focuses on the application of cold mixtures produced using bitumen emulsion as binder. By using cold mix asphalt, energy savings can be achieved of 95% compared to Hot Mix Asphalt (HMA) manufacturing. The weaknesses of cold mix asphalt are also apparent. Since water needs to dissipate from bitumen emulsion in order for the bitumen to develop adhesion with the aggregates, the cold mix asphalt may need several weeks to achieve its full strength [2].
This may result in lower primary strength and high porosity when compared with the conventional hot mix asphalt [3], [4] and [5]. In addition, the moisture damage is possible and the durability are of concern because of the existence of water in the mixture [6]. As a result, for heavy dusty pavements cold mix asphalt has seldom been used as a structural layer [7].

The addition of ordinary Portland cement with a proportion of (1-2) % (by mass) to cold asphalt mixture significantly improves its early mechanical properties [8] and [9], and the fully-cured material may acquire mechanical properties comparable or even better than those of an equivalent HMA [3], [10] and [11].

There are many types of by-product or waste materials which used instead of cement because they are cheaper than cement or even without cost, available, and environmentally friendly; like ground-granulated blast-furnace slag (GGBS) which is a by-product material from iron production, represented by a fine powdery material that resembles to Portland cement in its appearance.

2. Aim of the Research

To study the effect of adding Ground-granulated blast-furnace slag (GGBS) on the characteristics of CBEMs for binder course with different ages of 3, 7, 14 and 28 days.

3. Objectives of Research

The main objectives of this research are:
To encourage the use of cold bituminous emulsion mixtures CBEMs as an alternative to the conventional "HMA" in the construction of highways roads and for many causes like the simplicity of production, economic characteristic and environmental friendliness.
To investigate ways of enhancing the performance of CBEMs in particular mixtures incorporating selected by-product materials.
To encourage the use of the by-product materials such as Ground-granulated blast-furnace slag (GGBS) to improve the characteristics of mixture instead of costly materials such as cement.

4. Materials

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

4.1 Aggregates

The aggregates are categorized according to particle size into fine and coarse aggregates; the coarse aggregate used in this work is crushed aggregate from Al-Nibaie quarry and the fine aggregate from Najaf city. Routine tests are performed on the aggregates to evaluate their physical properties; the results are summarized in Table 1. The selected gradation with the specification limits are exhibited in Table 2 in accordance with the "general specification for roads and bridges [12], section R9.

| Material       | Property                         | Value |
|----------------|----------------------------------|-------|
| Coarse aggregate | Bulk specific gravity           | 2.78  |
|                 | Apparent specific gravity        | 2.82  |
|                 | Water absorption, %              | 0.61  |
| Fine aggregate  | Bulk specific gravity            | 2.69  |
|                 | Apparent specific gravity        | 2.73  |
|                 | Water absorption, %              | 1.60  |
| Mineral filler  | Particle specific gravity        | 2.71  |
Table 2. Selected binder course gradation [12].

| % passing by mass of aggregate | Sieve opening size, mm | Specification limits | Mid-limit gradation specifications |
|-------------------------------|----------------------|----------------------|-----------------------------------|
| % Sieve opening size (mm)     | Standard sieves (mm) |                      |                                   |
| 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                    |
| Filler                        | 3-9                  | 6                    |

4.2 Bitumen Emulsion
Cationic emulsified asphalt is used in this research in order to prepare all specimens of CBEMs. The properties of the used bitumen emulsion are shown in Table 3.

Table 3. Asphalt Emulsion Properties.

| Property                                      | Value                  |
|----------------------------------------------|------------------------|
| Residue by distillation, %                   | 60                     |
| Relative Density at 15 °C, g/cm³             | 1.05                   |
| Appearance                                   | Black to dark brown liquid |
| Residual bitumen penetration, 1/10 mm        | 100                    |

4.3 Mineral Filler
In this research, three types of fillers are used which are, material passing sieve No.200 (.075 mm), ordinary Portland cement (OPC), and Ground-granulated blast-furnace slag (GGBS).

4.3.1 Ordinary Portland Cement (OPC)
Ordinary Portland cement is supplied from AL-Kufa factory; in this research this filler (OPC) is used by various proportion i.e. 0, 2, 4 and 6% by total weight of aggregate. Chemical and Physical properties of (OPC) are shown in Table 4.

Table 4. OPC Physical and Chemical Properties.

| Physical Properties                                      | Value                  |
|----------------------------------------------------------|------------------------|
| Passing sieve No.200                                      | 95%                    |
| Density (gm./cm³)                                         | 3.12                   |
| Specific surface area (m²/kg)                             | 418                    |

| Chemical testing (XRF)                                     |                        |
|-----------------------------------------------------------|------------------------|
| CaO                                                       | 60.845%                |
| SiO₂                                                      | 24.564%                |
| Al₂O₃                                                     | 2.135%                 |
| MgO                                                       | 1.625%                 |
| Na₂O                                                      | 1.583%                 |
| Fe₂O₃                                                     | 1.131%                 |
| K₂O                                                       | 0.694%                 |
4.3.2 Ground-granulated blast-furnace slag (GGBS)
GGBS represents a by-product material and it is used by various percentages from total weight of aggregate as partial replacement of OPC. Chemical properties of GGBS are shown in Table 5.

Table 5: Chemical Properties of GGBS.

| Oxides          | GGBS |
|-----------------|------|
| SiO₂            | 30.7 |
| Al₂O₃           | 13.3 |
| Fe₂O₃           | 0.35 |
| CaO             | 42.4 |
| MgO             | 6.89 |
| Others          | 6.32 |
| Specific surface area (m²/kg) | 681 |

4.4 CBEMs’ Design Procedure
CBEMs specimens were designated depending on asphalt institute design procedure Ms-14 [13] which involves the following steps:

- Determination of Aggregate Gradation
  All specimens used in this research were prepared for all tests using the total mass of aggregate =1000 gm. (for one specimen) depending on the selected aggregate gradation that was shown in Table 2 (Selected Binder Course Gradation).

- Definition of Initial Residual Bitumen Content (IRBC) and Initial Emulsion content (IEC)
  The main step in the design procedure of the mixture was to calculate the estimated Initial Residual Bitumen Content (IRBC), selected as P, utilizing the Asphalt Institute empirical formula as shown below [13].

  \[
P = (0.05 A + 0.1 B + 0.5 C) \times (0.7)
  \]

  Where:
  
  \(P\) = the percentage of Initial Residual Bitumen Content (IRBC) by mass of aggregate.
  
  \(A\) = the percentages of coarse aggregate (retained on sieve 4.75 mm).
  
  \(B\) = the percentages of fine aggregate (passing sieve 4.75 mm and retained on sieve 0.075 mm).
  
  \(C\) = the percentages of filler (passing sieve 0.075 mm).

  The values of \((A, B)\) and \((C)\) were determined based on the selected aggregate gradation that was shown in Table 2, values of \((A, B)\) and \((C)\) were found to be (50%, 44%, and 6%) respectively.

  In an emulsion, the bitumen is suspended as tiny droplets in water. The value of IEC (Initial Emulsion Content) can be determined by dividing \(P\) by the percentage of the residual bitumen content in the emulsion, the content of residual bitumen in the emulsion that may be obtained by heating emulsion until whole water content evaporation, then calculation its percentage from total emulsion by using the formula as shown below:

  \[
  \text{IEC} = \left(\frac{P}{X}\right) \%
  \]

  Where:

  \(\text{IEC}\) = Initial Emulsion Content by mass of aggregate.

  \(X\) = the residual bitumen content of the emulsion

  According to the selected gradation and after application of the equation (3-1), the Initial Residual Bitumen Content was 6.93% by mass of aggregate. The base bitumen content in the used emulsion was 60%, thus, the IEC is (6.93/0.6)= 11.55% by mass of aggregate.

- Determination of Pre-mixing water content
  The coating degree of the aggregate and bitumen emulsion is primarily controlled by the pre-mixing water content, particularly when the aggregate gradation contains a high percentage of filler. Thanaya [16] reported that the best bitumen coating on aggregate can be achieved when the mixture is not too stiff or too sloppy. Various pre-mixing water contents were incorporated, i.e. (3–6 %) by mass of aggregate with Initial Emulsion Content (IEC), calculated from equations (1) and (2) (IEC=11.55 % by mass of aggregate), to mention the lowest content of pre-mixing water with sufficient coating. According
to the visual inspection, 3% pre-mixing water (30 gram) by mass of aggregate was chosen in preparation of CBEMs.

4.5 Preparation of Cold Bituminous Emulsion Mixtures (CBEMs)
Specimens of CBEMs were mixed by using the mixing machine shown in Figure (1). The aggregate and filler material with pre-wetting water content (3 % by mass of aggregate) were added and mixed for one minute at low speed. Then bitumen emulsion (11.55 % by mass of aggregate) was gradually added during the next 1 minute of mixing at the same speed, after that the mixing process was continued for one minute at high speed (total mixing time is 3 minutes). 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) shown in Figure (2) was used as the general compacting process with 75 blows to each face of the specimens.

![Mixing Machine](image1.jpg)

![Marshall Hammer Compactor](image2.jpg)

Figure 1. Mixing Machine.  
Figure 2. Marshall Hammer Compactor.

In this research, there are three specimens of cold mixture for each percentage that were designated and produced according to gradation for binder coarse that explained in Table 2 with a various percentages of filler by mass of aggregate (1000 gram), these mixture designation are shown in Table 6.

5. Testing
5.1 Marshall Stability (MS) Test
The test of stability for cold bituminous emulsion mixtures (CBEMs) utilises the same apparatus of Marshall Stability that used for testing hot mix asphalt (HMA). Generally, after preparation and compaction the sample had been modified so that the samples are tested for the curing (24 hour placed in the mold at lab temperature 30 °C) Then the samples are placed at lab temperature (30 °C) for (7days), after that tested in Marshall Apparatus shown in Figure 3.
Table 6. Mixture Designation, percentages of mineral filler in the mixture with selected test.

| Mix number | Percentage of mineral filler % by total aggregate mass | Materials passing sieve 0.075 mm from aggregate | OPC | GGBS | Selected Test |
|------------|--------------------------------------------------------|-----------------------------------------------|-----|------|---------------|
| 1          | 6                                                      | 0                                             | 0   | 0    | Indirect Tensile Strength |
| 2          | 4                                                      | 2                                             | 0   | 0    | Indirect Tensile Strength |
| 3          | 2                                                      | 4                                             | 0   | 0    | Indirect Tensile Strength |
| 4          | 0                                                      | 6                                             | 0   | 0    | Indirect Tensile Strength |
| 5          | 2                                                      | 2                                             | 2   | 0    | Indirect Tensile Strength |
| 6          | 0                                                      | 2                                             | 4   | 0    | Indirect Tensile Strength |
| 7          | 0                                                      | 2                                             | 6   | 0    | Indirect Tensile Strength |
| 8          | 0                                                      | 2                                             | 8   | 0    | Indirect Tensile Strength |
| 9          | 6                                                      | 0                                             | 0   | 0    | Marshall stability       |
| 10         | 6                                                      | 0                                             | 0   | 0    | Index of Retained Strength |
| 11         | 4                                                      | 2                                             | 0   | 0    | Marshall stability       |
| 12         | 4                                                      | 2                                             | 0   | 0    | Index of Retained Strength |
| 13         | 0                                                      | 2                                             | 6   | 0    | Marshall stability       |
| 14         | 0                                                      | 2                                             | 6   | 0    | Index of Retained Strength |

5.2 Indirect Tensile Strength (ITS) Test

Indirect Tensile Strength (ITS) test was conducted according to the method that designated by ASTM D 4123 [14]. The experimental procedure used to determine tensile, or splitting, strength of a cylindrical specimen is based on loading it diametrically in compression with a constant rate of 50.8 mm/min (2
in./min) to generate a tension zone along the specimen’s loaded diameter. The expression for the maximum tensile strength generated can be stated as:

\[ \sigma_t = \frac{2P_{\text{max}}\pi H D}{\pi H D} \]  

(3)

Where:
- \( \sigma_t \) = the ITS in kPa
- \( P_{\text{max}} \) = maximum applied load in KN
- \( H \) = the height of specimen in m
- \( D \) = the diameter of specimen in m

The test of indirect tensile strength (ITS) for CBEM specimen is conducted after sample compaction, and tested for curing (24 hour placed in the mold (at laboratory temperature 30 ºC)). After that placed at lab temperature (30 ºC) for (3, 7, 14 and 28) days according to the selected test age before implementing the (ITS) test by Marshall apparatus as shown in Figure (4).

![Figure 4. Testing of Indirect Tensile Strength (ITS).](image)

5.3 Index of Retained Strength (IRS) Test

Index of Retained Strength (IRS) is used to evaluate the moisture damage of the control and modified CBEMs. This test was conducted according to ASTM D 1075 which is called as "Effect of Water on Cohesion of Compacted Bituminous Mixtures". In this study, indirect tensile strength (ITS) had been used to determine the index of retained strength (IRS) for the control and modified asphalt mixtures. In this test, two sets of samples were prepared and separated. The first set, dry samples, that after the preparation and compaction placed in the mold for 24 hour (at laboratory temperature 30 ºC), after extracting the samples from the mold, they were placed in the lab temperature (30 ºC) for 7 days before implementing indirect tensile strength (ITS). The second set, wet samples, with the same conditions of the first set, except after extracting the samples from the mold they were placed in the lab temperature (30 ºC) for 4 days and then placed in the water bath, at 40 ºC for three days, then the samples were extracted from water bath and placed at lab temperature (30 ºC) implementing indirect tensile strength (ITS). Figure 5 shows the water bath used for conditioning.
The value of index of retained strength (IRS) can be calculated by applying equation : (ASTM D 1075)

\[ IRS = \frac{S_2}{S_1} \times 100\% \]  

Where:
IRS = Index of Retained Strength, %

\[ S_1 = \text{indirect tensile strength (ITS) of the dry specimens, kps} \]
\[ S_2 = \text{indirect tensile strength (ITS) of the wet specimens, kps} \]

6. Results and Discussion

This paragraph presents the obtained results showing the extent of the impact of Ordinary Portland Cement (OPC) and GGBS on improving cold bituminous emulsion mixture (CBEMs).

6.1 Influence of OPC Addition on Indirect tensile strength (ITS) Results

Indirect Tensile Strength (ITS) is an important test that should be conducting on cold bituminous emulsion mixture (CBEMs) to indicate the tensile strength of a cylindrical specimen. Figure (6) shows the Influence of Ordinary Portland cement (OPC) addition on ITS. Different percentages where added as a replacement to the mineral filler which were 2, 4 and 6% OPC by total weight of aggregate.

6.2 Determination of Optimum GGBS content

Four percentages of GGBS were added as a filler to the cold bitumen emulsion mixtures (CBEMs) containing 2% OPC which were 2, 4, 6 and 8% by total weight of aggregate. The specimens were
prepared and tested to indicate Indirect tensile strength values. ITS was adopted to indicate the optimum content of GGBS. The results are shown in Figure (7).

![Figure 7. Indirect tensile strength for CBEMs with GGBS.](image)

Figure 7 shows ITS values for cold mixtures with different percentage of GGBS. It is clearly shown that Indirect tensile strength of mixture increased significantly with increasing of GGBS percentage. This increment was sharply until 6% of GGBS percentage then it has been decreased slightly. The percentage of increment for the mixtures with 6% GGBS was more than 160% in comparison with the control mixtures (which used aggregate dust as filler) and almost 73% in comparison with the cold mixtures containing 2% OPC. It’s worthy to say that these mixtures i.e. containing 2%OPC+6%GGBS have Indirect tensile strength more than those mixtures that have 6% OPC which is a very promising finds by means of mechanical, economical and environmental points of view. So, in accordance to these results, the optimum content of GGBS can be adopted to be 6% by total weight of aggregate.

6.3 Effect of GGBS on Indirect Tensile Strength (ITS)

Four mix used to study the effect of addition of GGBS on Indirect Tensile Strength, after different periods of time i.e. 3, 7, 14 and 28 days. The results are shown in Figure 8.

![Figure 8. Effect of OPC % and GGBS % on Indirect Tensile Strength (ITS) of CBEM.](image)

Figure 8 shows the relationship between mix type and ITS, whereas ITS equal to 195 kPa for control mixture with (6 % materials passing sieve No.200) for age (7days) increased about 50%, 107% for cold
mixtures containing (2% OPC and 4% materials passing sieve No.200) and for mixtures with 6% OPC respectively. Also ITS increased about 160% for cold mixtures containing 2% OPC and 6% GGBS (Optimum GGBS content). Figure 8 also shows that the amount of increase in ITS (kPa) is rapid in the early ages of the mixing (3 and 7) days and then continues to increase slightly, due to the evaporation of water found in the mix in early ages and gaining strength.

6.4 Influence of GGBS Addition on Marshall Stability (MS)
Marshall Stability is an important property for the performance of asphalt mixture in the binder course design. It shows the ability to resist shoving, rutting and give layer the adequate stiffness under traffic. The results of the cold mixtures with different percentages of OPC and GGBS are shown in Figure (9).

![Figure 9. Influence of OPC % and GGBS % on Marshall Stability (MS) of CBEMs.](image)

Figure 9, shows Marshall Stability (MS) values for cold mixtures with percentage of GGBS. It is clearly shown that Marshall stability of mixture increased significantly with 6% percentage of GGBS. The percentage of increment for the mixtures with 6% GGBS was more than 220% in comparison with the control mixtures (which used aggregate dust as filler) and almost 52% in comparison with the cold mixtures containing 2% OPC. It’s worthy to say that these mixtures i.e. containing 2% OPC+6% GGBS have Marshall Stability more than those mixtures that have approximately 6% OPC which is a very promising finds by means of economic and environment.

6.5 Effect of GGBS on Index of Retained Strength (IRS)
Index of Retained Strength (IRS), also called water sensitivity is adopted to assess the moisture damage of the control and modified CBEMs. Figure (10) shows ITS for these mixtures before and after exposing to the water.
Effect of OPC % and GGBS % on Index of Retained Strength (IRS) of CBEMs.

Apparently in Figure (10) the IRS equals to 20% for control mix with (6% material passing sieve No.200) which is very low. IRS increased to reach (64, 77 and 87) % for mixtures with (2%, 6%) OPC and 2%OPC+6%GGBS, respectively. This finding can be attributed to that another binder has been developed which is from the hydration process between the cementitious material and the trapped water.

7. Conclusions

This study was involved in the activation of (OPC) with ground-granulated blast-furnace slag (GGBS) which can be included to produce a new binder course cold asphalt mixtures. This study led to the following conclusions:

1. Ordinary Portland cement (OPC) significantly increases Indirect tensile strength (ITS) of mixture, whereas when OPC was added by 2, 4, and 6% by total weight of aggregate, ITS (at 7 days) increased by approximately 50, 80 and 107% respectively in comparison with control mixture.
2. In accordance to the ITS test results at different ages (3, 7, 14 and 28) days, it was found that most of the strength gained for mixing was at early ages i.e. 3 and 7 days. Then, the mixtures continued to gain strength but at a lower rate. Therefore, the strength gained during the first 7 days equals 90% of the strength at the age of 28 days.
3. GGBS can be utilized as a filler instead of (OPC) to improve the mechanical properties of the mixture. When, GGBS was added by 2, 4 and 6% by total weight of aggregate, the performance of mixture improved significantly.
4. The optimum content of GGBS can be reported as 6% that corresponds high value of Indirect tensile strength (ITS) after this value there was a very slight decreased.
5. Optimum content of ground-granulated blast-furnace slag (GGBS) increases Indirect tensile strength (ITS) about 160% in comparison with control mixture and this value corresponds to those mixtures with almost 6% OPC at 7days. So, using GGBS has a very economic and environmental impact.
6. Marshall Stability (MS) for cold mixtures prepared with optimum content of ground-granulated blast-furnace slag (GGBS) increased about 220% in comparison with control mixture.
7. By means of water damage, IRS for cold mixtures containing 6% GGBS improved by 335% in comparison with the control mixtures.
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