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# Laboratory investigation on effects of microwave heating on early strength of cement bitumen emulsion mixture

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## HIGHLIGHTS

- Temperature variation of CEAM under microwave irradiation was tested.
- Early strength of CEAM under microwave irradiation was studied.
- Cement hydration and emulsion breaking under microwave irradiation was analyzed.
- Regression model between CEAM strength and various factors was developed.
- Microwave heating is recommended to improve early strength of CEAM.

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## ABSTRACT

Effects of microwave heating time, microwave power, water-cement ratio (W/C) and bitumen-cement ratio (B/C) on early strength of cement bitumen emulsion mixture (CBEM) were studied in this work. Environment scanning electron microscopy (ESEM) and Fourier Transform infrared spectroscopy (FT-IR) were adopted to analyze microstructures and compositions of CBEM. The most important factors affecting CBEM strength were putting forward based on multiple linear regression analysis (MLRA) and grey correlation analysis (GCA). The results show that the total microwave energy is composed of microwave power and microwave radiation time. The higher the total microwave energy, the higher the surface temperature of CBEM. The effect of W/C on CBEM temperature is more significant than that of B/C. Microwave heating time and microwave power can evidently influence strength of CBEM. Microwave heating can promote cement hydration, which is beneficial to improve strength of CBEM. However, excessive microwave time can result in the decrease of CBEM strength. Temperature model based on MLRA can show linear correlation between different factors. Strength model shows quadratic correlation to microwave parameters. In summary, reasonable microwave heating is an effective technique to improve early strength of CBEM.



## 1. Introduction

Cement bitumen emulsion mixture (CBEM) consists of bitumen emulsion, cement, aggregate, water and some admixtures. It combines rigid mechanical properties of cement and deformation performance of asphalt. Due to advantages of energy savings, convenient storage and pollution-free environment, it has been widely used as repair materials in road maintenance engineering [1]. However, in order to exert all the strength of the mixture, the emulsion needs to be broken and the interstitial water needs to evaporate, which can take two months. The evaporation of moisture in the cold mix asphalt follows the process: in the first stage, the mixture is completely saturated; in the transition phase, the capillary connecting the saturation zone and the mixture surface gradually collapses; in the second stage, the surface dry layer is formed, and the remaining water evaporates from inside the mixture. The evaporation kinetics test showed that the partially saturated region constituting the film region traveled from top to bottom at a reduced rate, which indicated that the drying process slowed down over time. Moreover, the emulsion is a component that delays the evaporation of water and gradually reduces the hydraulic conductivity over time [2]. The water evaporation rate

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is related to the boundary conditions, such as temperature and relative humidity [3]. When the water consumption of the mixture is high, the water loss in the initial solidification stage is faster [4]. Therefore, it is difficult for cement bitumen emulsion mixture to meet the needs of fast open traffic in road engineering [5,6].

In recent years, there are some studies on properties of CBEM. The increase of cement content is an effective way to improve strength of CBEM [7,8]. The hydration of cement can improve mechanical properties of the mixture, consume water and accelerate emulsification of bitumen emulsion [9,10]. Some scholars found that early strength of CBEM was mainly influenced by B/C [11]. As B/C increases, the working performance and compressive strength of CBEM are significantly reduced [12]. B/C also determines whether the mechanical behavior is cement dominated or asphalt dominated; and the transition to cement dominated to asphalt dominated mechanical behavior occurs when B/C is between 1 and 2 [13]. The emulsifier content affects the mechanical behavior by affecting the amount of water retained in the sample. At high emulsifier contents, a relatively high level of water is retained in the mixture, which can possess more cement hydrates and better mechanical properties [14]. The temperature for curing is also a factor that affects early strength of CBEM. With the increase of curing temperature, early strength of CBEM increases [15]. Water content also significantly affected the performance of CBEM mixture [16]. However, excessive cement dosage and curing temperature are not conducive to durability of the mixture and it is easy to shrinkage cracking [8,15].

Nowadays, the application of microwave technology in the maintenance of asphalt pavement has received more and more attention [17]. Microwave de-icing technology has been introduced into de-icing and snow removal systems [18]. In order to enhance microwave absorbing properties of the mixture, it is a very effective method to add a strong absorbing material such as synthetic carbon fiber to the mixture and steel fiber [19,20]. In addition, vehicles for microwave heating work have been well developed [21], which provides equipment availability for microwave heating mixture.

In addition, microwave heating is very effective for the separation of oil-in-water emulsions [22]. In contrast to conventional heating, microwaves have many advantages, including higher thermal efficiency, fast thermal response, phase selective heating, and no direct contact with liquids [23]. The exposure to the emulsion to microwave electromagnetic fields causes molecular rotation and ion conduction of the dispersed aqueous phase (but does not cause changes in molecular structure), oil phase viscosity decreases (due to increased temperature), due to increased internal pressure during irradiation. The expansion of the water droplets promotes contact between the droplets, which in turn accelerates the demulsification and improves the separation productivity, thereby improving the thinning process of the interface film. The resulting molecular rotation is responsible for internal heating, neutralization of the internal phase of the zeta potential and destruction of hydrogen bonds between the surfactant and the water molecules, which occur when the stability of the emulsion decreases. As a result, the main mechanism by which microwave heating enhances the emulsion demulsification ability is attributed to its thermal effect [24]. The optimization of the microwave-induced demulsification is usually based on the microwave power and time. In general, the higher the microwave radiation power, the faster the emulsion breaks, the more the phase separation is [25]. In addition to the microwave parameters, different oil content can affect the microwave heating efficiency, thus affecting the efficiency of the microwave demulsification [26,27].

The purpose of this study is to find out the variation on early strength of CBEM heated by microwave and to put forward the key factors affecting the early strength of CBEM. For this purpose, the changes of surface temperature and early strength of CBEM under different microwave parameters (microwave power, microwave time) and material composition (W/C and B/C) were studied. The microstructure and composition changes of CBEM before and after microwave heating were analyzed by ESEM and FT-IR. Finally, mathematical model between CBEM intensity and various factors (W/C, B/C, microwave power and microwave heating time) is established by using multivariate linear regression theory to predict early strength of CBEM.

## 2. Raw materials and test methods

### 2.1. Raw materials

The bitumen emulsion is a cationic emulsion with original asphalt as the raw material with mass fraction of 60%. The amount of emulsifier used was 1.2% and the pH of the aqueous phase was 2.8. The obtained bitumen emulsion possessed density of about 1.022 g/cm$^3$. The properties of bitumen emulsion used in the mixture are shown in Table 1. Ordinary Portland cement was used and its properties are shown in Table 2.

The mixing water was tap water. Silicone deformer was used as antifoaming agent. Limestone was used as aggregate and its gradation is shown in Fig. 1. In the mixture, the weight of the binders (cement and emulsified asphalt) remains unchanged. E/C is the ratio of emulsion to cement and B/C is the ratio of asphalt to cement contained in the emulsion. The water in water-cement ratio is total water content, which includes free flow water and water existing on bitumen emulsion. In this work, the water cement ratio, asphalt dosage, microwave power ($P_M$) and microwave heating time ($T_M$) were changed by experiments. All test parameters of CBEM are listed in Table 3.

### 2.2. Experimental

Bitumen emulsion and water were mixed at slow speed (140 r/min) for one minute with a mixer. An appropriate amount of defoaming agent was added to eliminate the bubbles. Then cement was slowly added. The feeding time of the aggregate is not >30 s. After the feeding is finished, the mixture was mixed at high speed (285 r/min) for 2 min; and finally the mixture is mixed slowly for 30 s to eliminate large bubbles. Cement emulsified asphalt mixture was poured into a vessel dedicated for the heating by microwaves and heated. Finally, the fresh mixture was poured into a special test mold of 40 mm × 40 mm × 160 mm. Thereafter, the mold filled with the mixture was compacted. The compaction was divided into two parts. First, the mixture was compacted under displacement control conditions, after which it was compacted under force control conditions while maintaining maximum force. Compaction process can reduce excess moisture and bubbles in the mixture and improve the compactness of the mixture. After 24 h, the mold was removed. The obtained test piece was a cuboid sample with length of 160 mm, width of 40 mm and height of 40 ± 0.1 mm. CBEM samples were cured in curing room with a temperature of 20 °C and a relative humidity of 90% for 3 days and 7 days. The flow chart for the preparation of the CBEM samples is shown in Fig. 2.

#### 2.2.1. Surface temperature test

The surface temperature of CBEM heated in microwave oven was measured by Fluke TiS75 thermal imaging camera. Fig. 3 shows the temperature measurement of CBEM. The test procedure is as follows: First, the initial temperature of the mixture is recorded at room temperature; then the mixture is placed in a microwave oven and heated for a predetermined period of time;