

THE EFFECT OF COMPACTION DELAY AND RATE OF STRENGTH GAIN ON COLD BITUMINOUS EMULSION MIXTURES

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Abstract.

Cold bituminous emulsion mixtures (CBEMs) are suitable for small scale jobs such as road maintenance works. When works are located at different locations, delay in compaction after mixing is inevitable. CBEMs are also weak within their early life strength, as it contains water. The objectives of the investigation were to study the effect of compaction delay and the rate of strength gain of CBEMs cured outdoors. It was found that the CBEMs, with or without cement, preferably to be compacted soon after mixing. When there is a delay in compaction, the loose mixture should be kept in a sealed container and to be compacted within 24 hours (without cement) or after 24 hours when incorporating cement (rapid setting cement-RSC). Addition of 2% of RSC by mass of aggregates significantly improves stiffness, and stiffness of 2000 MPa targeted was achieved within less than two weeks.

Keywords:

cold mix, compaction delay, strength gain.

INTRODUCTION

It had been recognized that in general CBEMs are simple to produce and suitable for low to medium traffic conditions; works in remote areas; and for small scale jobs (at numerous locations) such as reinstatement works. However, currently there is no universally accepted mix design method for CBEMs (Leech, 1994). The CBEMs were produced by adopting a simplified design (which was considered more practical) previously proposed by the author for CBEMs (Thanaya and Zoorob, 2002). As CBEMs are suitable for small scale works which may be located at different locations, therefore it is very possible that there can be a delay in compaction after the mixtures were mixed.

Until now, cold bituminous emulsion mixtures (CBEMs) are considered inferior to hot asphalt mixtures. This is due to three main concerns with respect to CBEMs, namely: high air void; weak early life strength (caused mainly by the trapped water) ; and the long curing times (evaporation of water/volatiles content and setting of the emulsion) required to achieve maximum performance. Studies by Chevron Research Company in California, concluded that full curing of cold bituminous mixtures on site may occur between 2 and 24 months depending on the type of emulsion used and weather conditions (Leech, 1994).

The objectives of the investigation were to study the effect of compaction delay and the rate of strength gain of CBEMs cured outdoors. It was targeted to achieve minimum stiffness value (Indirect Tensile

Stiffness Modulus - ITSM) of 2000 MPa (Milton and Earland, 1999).

METHOD

Aggregate Gradations for the Mixtures

The aggregate gradations of all the design mixtures used in this investigation were based on a modified Fuller's curve using a formula proposed by Cooper (Cooper et al, 1985) as shown below:

$$P = \frac{(100 - F)(d^n - 0.075^n)}{D^n - 0.075^n} + F \dots\dots\dots [1]$$

where: P = % material passing sieve size d (mm), D = maximum aggregate size (mm), F = % filler, n = an exponential value that dictates the concavity of the gradation line. The n value used was 0.45 which is an exponential factor that can give good aggregate packing (Thanaya, 2003). The value selected for F was equal to 4 %, which satisfies the allowable limits for filler content in Dense Bitumen Macadams (BS 4987, 2003).

Materials Used

The constituent materials used for the CBEMs and their properties are given in Table 1. The binder used for the CBEMs was a cationic bitumen emulsion (60 % bitumen content) with 100 pen. grade base bitumen obtained from Nynas Bitumen Ltd., UK. The specific gravity of the base bitumen was 1.02. The maximum aggregate size selected for all the CBEMs was 12.0 mm. The gradation of the CBEMs is plotted in Figure 1.

Table 1. Materials used for the CBEMs.

Material	Density (g/cm ³)	Water Abs. (%)	Usage
Limestone	2.65	1.0	Coarse aggregate
Crushed glass	2.51	< 0.5	Coarse and fine aggregate
Red porphyry sand (RPS) *	2.59	0.9	Fine aggregate
Fine asphalt sand	2.66	0.8	Fine aggregate
Fly ash (Eggborough PS)	2.20	-	Filler

** by-product of aggregate crushing. ** PS = Power Station.

This gradation is within the limits recommended by the American Asphalt Institute (Asphalt Institute, 1989). The optimum residual bitumen content of the CBEMs was already designed at 6 % (Thanaya, 2003).

Mixture Designation

Depending on the material types incorporated, the CBEMs were designated as shown in Table 2.

Table 2. Mixture designation and composition of the CBEMs

Mixture type	Coarse aggregates (56.61 %)	Fine Aggregates (39.39 %)	Filler (4 %)
CBEM-0	Limestone	Red porphyry sand (RPS)	Fly ash
CBEM-1	Limestone	60 % red porphyry sand (RPS) and 40 % quartzite sand.	Fly ash
CBEM-2	Limestone + crushed glass	Quartzite sand + crushed glass	Fly ash

The coarse aggregates for all mixtures were composed of the following fractions (12-10mm), (10-5mm), (5-2.36mm), and the fine aggregates were of particle sizes (2.36-0.075mm). All filler material passed 0.075mm.

As shown in Table 2, three types of CBEMs were produced. Initially CBEM-0 mixtures were made. It was found that some aggregate particles of CBEM-0 mixtures were not fully coated with bitumen emulsion. Although cationic bitumen emulsion was recommended to be compatible with most aggregates (Leech, 1994), this was certainly not found to be the case with the red porphyry sand (RPS) used in this investigation. It had been known that there can be aspect of affinity between bitumen emulsion and aggregates which can be affected by the surface charges of the materials (Leech, 1994). In order to improve the degree of coating, in the CBEM-1 mixtures (as shown in Table 2), the fine aggregates were of a combination of a maximum 60 % red porphyry sand (RPS) and 40 % quartzite sand. This composition was based on coating test trials.

CBEM-2 incorporated 30% crushed glass by weight of total aggregates and was composed of (60 % 5-2.36mm particles + 40 % passing 2.36mm). This was based on the availability of the crushed glass particle sizes. Replacement levels of up to 30% by mass of aggregates in hot mixtures (Glasphalt) have already been successfully tested in full-scale trials in the UK with encouraging performance results (Nichols and Lay, 2002).

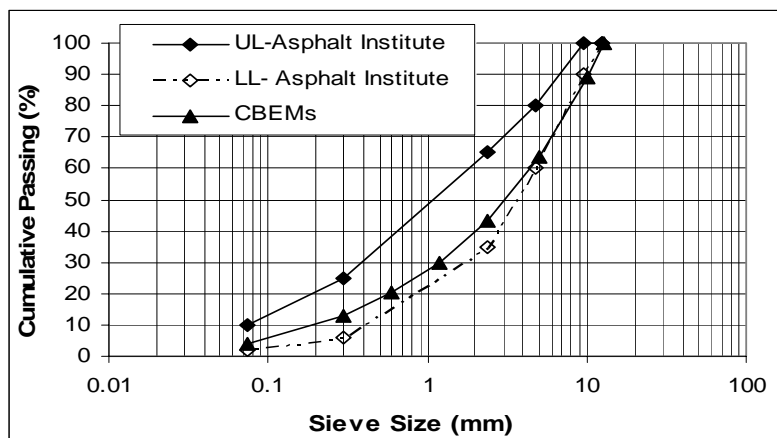


Figure 1. Aggregate Gradation of the CBEMs compared with the American Asphalt Institute gradation (UL=upper limit; LL=lower limit).

In cases where an accelerated rate of strength gain was desired, 1 to 2 % cement by mass was added to the mix to accelerate the curing process. Rapid setting cement (RSC) was found to give faster rate of strength gain compared to other type of cement (Thanaya, 2003).

RESULTS AND DISCUSSION

Mixture Production and Mechanical Properties Tested

As there is no universally accepted design mixture for CBEMs. The mixtures were produced by adopting a simplified CBEMs design procedure introduced by the author (Thanaya and Zoorob, 2002). The design procedure proposed overcomes the impractical requirement of the determination of optimum water content at compaction on site. It ensures that the air void requirement is met; the retained stability is evaluated at optimum residual bitumen content only, which reduces the number of samples needed; and provides data on the ultimate strength of the CBEMs under full curing conditions. Compaction of the CBEM specimens was carried out using a Gyropac compactor set at 240 kPa axial pressure (for 100 mm diameter samples) with an angle of gyration of 2°.

Following several compaction trials with the Gyropac, it was found that in order to achieve the target air void content of 5 to 10% the compaction level had to be increased by up to 2 times the 'Heavy' compaction level routinely specified (120 revolutions in the Gyropac, which is equivalent to the compaction effort generated when applying 75 blows each end using a Marshall hammer). This higher compaction level was subsequently referred to as 'extra heavy compaction'.

Laboratory curing of the CBEMs was carried out in an oven set at 40°C. Full curing conditions were achieved when the specimens, following repeated

weighing, maintained a constant mass. Typically, full curing conditions were achieved within 18 to 21 days for samples with air void values in the range 8 to 9 % (Thanaya, 2003).

The mechanical properties tested were: the indirect tensile stiffness modulus (ITSM) at 20°C. The machine used was using a universal Materials Testing Apparatus (MATTA). In this test the samples were subjected to vertical dynamic loadings, due to which the horizontal strains were recorded to enable the determination of ITSM (BS-DD-213, 1993).

Effect of Compaction Delay on CBEMs

This part of the investigation was intended to evaluate the effect of compaction delay on CBEMs. The length of delay is a variable and depends on the scale of the proposed works. In practice, it is important to be able to store loose CBEMs for small scale works, e.g. road maintenance operations performed at various locations along a section of road.

The CBEMs wet loose mixture were lightly air dried to avoid clumping, then stored in a sealed container for 0, 3, 6, 24, and 48 hours before compaction. The compacted samples were then fully cured in an oven at 40°C (until a constant mass was achieved). Two types of mixtures were tested: mixtures without cement and mixtures with 2% cement (rapid setting cement-RSC). Test results of air voids and ITSM values at 20°C of the fully cured compacted samples are presented in Figures 2 and 3. As the loose mixtures were lightly air dried before they were stored in a sealed container, very little water was squeezed out during the compaction process.

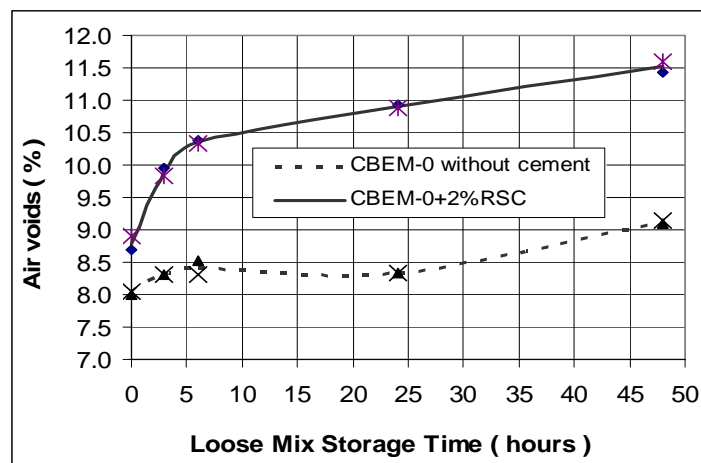


Figure 2. Air voids of fully cured compacted CBEM-0 vs. loose mixture storage time.

Note: RSC (rapid setting cement).

Figure 2 illustrates that as the mixtures became stiffer hence less workable during compaction in line with storage time, therefore the air voids increases. CBEM-0 mix that incorporate cement were less workable than without cement (rapid setting cement-RSC), which was indicated by higher air voids.

As the emulsion sets with increasing curing time, this results in an increase in compacted air void with increased storage time. The air void of the CBEM-0+2% rapid setting cement (RSC) gave higher values for all storage times of the loose mixture with a smaller difference recorded within the first 6 hours. These higher values are due to the hydration of cement in the presence of moisture. This causes the loose mixture to be somewhat stiffer and less workable during compaction when compared with the mixture without cement.

Figure 3 shows that the ITSM values of the CBEM-0 mixture (fully cured with no cement) remain relatively unchanged up to 24 hours storage time with a very gradual reduction beyond one day storage. The ITSM values of the fully cured CBEM-0+2% rapid setting cement (RPS) on the other-hand were overall greater than the mixture without cement at all storage times. However, there is a very noticeable reduction in ITSM values within the 3 and 6 hour loose mixture storage times.

It is interesting to note that the highest ITSM value for the mixture with cement was obtained when the wet mixture was compacted immediately following the mixing process (time 0 hour after mixing). This matter was not fully investigated; however, it is analyzed based on logical point of view.

The results suggest that when the mixtures were compacted within a very short time of the cement being added, the mixtures would be still most

workable during compaction. The cement hydration products would have been allowed to form in the available spaces between the mineral aggregates (VMA) within the compacted samples, hence the hydration products act as bonds between the aggregate particles. Simultaneously, they form wedges of hydrated cement-fines mortar which lock the aggregate skeleton in place.

Due to hydration, the crystalline cementitious products form mainly in the first 6 hours. Therefore, any delay in compaction from (time 0) will allow more hydration products to form in the loose wet mixture. This delayed compaction during the first few hours (up to 6 hours in this case) would have cause damage/breakage/pulverizing of these relatively weak crystalline formations, which results in a reduction in bond between the mineral aggregate particles and hence lower ultimate ITSM. (It is similar to having increased the fine aggregate content of the mixture.)

After the 24 and 48 hours loose mixture storage times, the majority of the cement hydration process would have taken place and the cementitious mortar formed would have become hard or tough enough, any damage to the bonds between the crystalline phase and the mineral aggregates during compaction should have greatly reduced. Since the hardened cement phase occurs (as irregularly shaped wedges) in the interstices between the larger mineral aggregate particles, it is logical that when these mortar wedges were partially broken in to medium sized particles, the increased roughness of the mixture (which was evident from the increased specimen air voids) provides an improvement in the aggregate interlock. Also, with the higher angle of internal friction that is present in these mixes due the hydrated cement particles this results in greater values of ITSM.

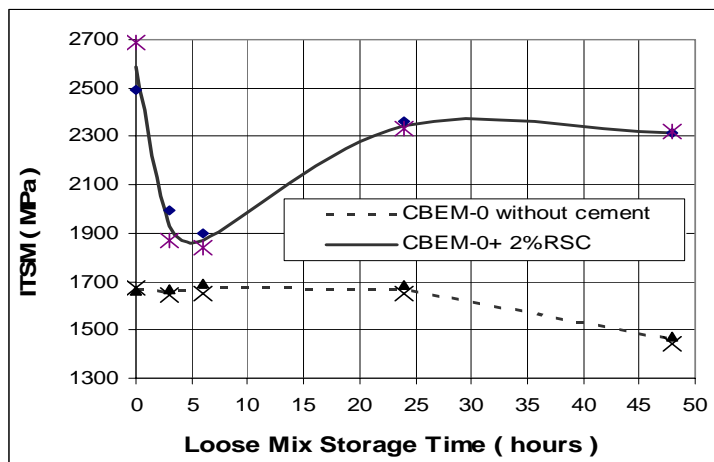


Figure 3. ITSM of fully cured compacted CBEM-0 vs. loose mixture storage time.

Evaluation of The Rate of Strength Gain of The CBEMs Cured Out Door

Samples of CBEM-1 mixes, without and with 2% rapid setting cement (RSC) were manufactured and cured in 'out-door exposure conditions' (full exposure to rain and actual temperature profiles) in order to better simulate site conditions. This was carried out to evaluate the mixture's realistic 'rate of strength gain' with time. Following compaction, the samples were kept in their moulds for 24 hours at 24°C room temperature prior to extrusion. The sides of the samples were then sealed with plastic adhesive tape and the taped samples were then placed on a flat metallic surface outdoors (on the roof of the School of Civil Engineering building, Leeds University), as shown in Figure 4.



Figure 4. Outdoor curing of CBEM samples.

This treatment was aimed to simulate realistic site curing conditions where the evaporation of water will predominantly occur through the surface of the mixture.

Outdoor curing began in February 2002, with an average outdoor temperature of 10°C. Rain, which

was a very frequent occurrence during the specimens curing period resulted in a slight wear of the surfaces of the samples. However, the samples remained intact and in good shape. At regular intervals, two samples were selected for testing.

Contrary to British Standard recommendations, each sample was tested for ITSM at 20°C only once, in order to avoid damage (as had been experienced) when a sample is subsequently tested at a later age. The samples were tested at ages: 1, 2, 4, 6, 8, 10, 12 and 24 weeks. The rate of strength gain (in terms of ITSM at 20°C) of the samples is shown in Figure 5.

With respect to outdoor curing, samples with no added cement gained strength slowly with time (as shown in Figure 5). The ITSM target of 2000 MPa (Milton and Earland, 1999) was only achieved after an estimated 16 weeks of outdoor curing. On the other hand, samples with 2% rapid setting cement (RSC) showed greatly improved performance, since they required less than 2 weeks of curing time to meet the ITSM target of 2000 MPa.

Stiffness values were not tested beyond 24 weeks (6 months), but the trend shown in Figure 5 does indicate a much more gradual but continued gain in stiffness. In either case, the rate of strength gain was 'relatively' fast when compared with some CBEM site trials without cement which required much longer curing times: 2 to 24 months (Leech, 1994). Direct comparison with other full scale cold mix surfacing investigations is not possible as the mixtures in the field are influenced by various factors, including; compaction level, climatic conditions: rainfall, surface drainage, traffic conditions, etc.

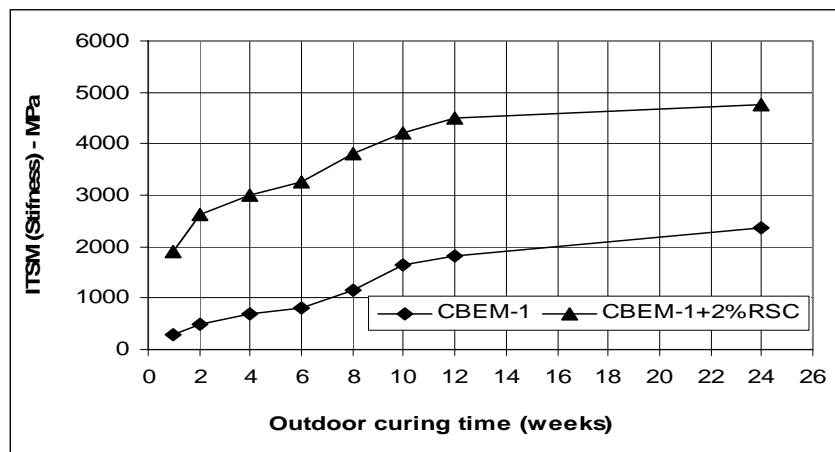


Figure 5. Rate of strength gain of CBEMs samples cured outdoor.

CONCLUSIONS

The main conclusions drawn from this investigation are as follows:

1. The CBEMs preferably to be compacted soon after mixing (with or without cement), in order to maximize the results and to avoid workability problems. If this is not possible the loose mixture should be kept in a sealed container and to be compacted within 24 hours (without cement), or after 24 hours when incorporating cement (Figure 3).
2. The addition of 2% cement (rapid setting cement-RSC) by mass of aggregates into the CBEMs cured out door significantly improves the stiffness (ITSM) of the CBEMs, and ITSM of 2000 MPa was achieved within less than two weeks (Figure 5).

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