Effects of construction time on the performance of cement treated base

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Abstract. Cement treated base (CTB) has been widely used as a stabilized base layer in pavement for highways, roads, airports, parking areas and some storage areas. CTB comprises mainly three components, namely, cement, water and either natural soil or aggregates. The mixture will become strong and durable after proper compaction and curing. CTB can be produced in central plant, haul to the laying area by dump trucks or can be mixed in-place using proper materials and equipment. One of the key factors which can affect the performance of CTB is the construction time which consists of mixing to transportation, laying and compaction. This paper describes a study that was conducted to analyse the effects of construction time on the performance properties of CTB. Laboratory tests were conducted for various CTB mixtures. The CTB mixtures were compacted at different time frames and then tested for dry density and unconfined compressive strength. The results were then analysed to study the effects of construction time.

1. Introduction
Using CTB as pavement base layer compared to unbound aggregate base layer is mainly benefited in durability (Gregory et al, 2006). The design, production and construction of cement treated base layers will be based on specific standard procedures and required performance properties. However, the materials characteristics, site conditions, climate and construction procedures can affect the performance properties of CTB. Well-designed CTB is crucial to achieve specified performance and construction of CTB is equally important as well. CTB can be produced in two different ways such as mixed-in-place and mixed at central plant. When comparing the two types of production, CTB produced at central plant gives better mix under close control but highly depends on construction procedure to achieve accomplishment (Gregory, et al, 2006). The CTB mix produced at central plant needs to be transported by tipper truck to site area to lay and then compacted to the desired density. In plant mix CTB, construction procedure, time for transportation, laying, compaction after mixing are important factors which can influence the mechanical properties of CTB. As the cement in the CTB starts to interact with water, the hydration process begins. Thus it is crucial to minimize the time between mixing and compaction. Moreover, when moisture in the mix is lost by delay in compaction, the fresh materials become harder and difficult to compact. Furthermore, the bond between the aggregates and cement binder is broken and resulting in the lower strength (Gutherie and Maile, 2010). According to the Portland Cement Association (Gregory et al., 2006), the recommended compaction time after mixing CTB is within 2 hours. Nonetheless, some factors can cause delay in compaction and exceed the recommended time of 2 hours. This study aims to analyse how construction time affects the performance of plant mixed CTB.
2. Background
As previously mentioned, the construction process of CTB layers is as critical as mix properties which can affect the performance of the constructed CTB layers. Practically, the CTB mixing plant is set up within a short distance from the site area to minimize transport time. CTB mixes are transported by tipper trucks with proper cover to minimize moisture loss, lay at the site by highly efficient continuous paving method to minimize the paving time, and compacted by roller (as shown in figure 1) to achieve the specific degree of compaction. However, there are unforeseen conditions which can cause delay in compaction. These include longer distance to transport due to changes in site conditions, larger or longer area of paving, breakdown or error at mixing plant, machinery breakdown, etc. As such, this study aims to investigate how compaction time could affect the performance of CTB.

![Figure 1. Laying and Compaction of Cement Treated Base.](image)

3. Methodology
The CTB samples were designed according to the Federal Aviation Administration (FAA) Advisory Circular 150/5370-10G (FAA, 2014). A mixture of coarse and fine granite aggregates were used to prepare the CTB samples and the gradation limits for the combined aggregate gradation is shown in table 1. Ordinary Portland cement was used for the CTB mixing. To evaluate the effects of compaction timings, the CTB samples were compacted at different time intervals after mixing with the cement. A total of six batches of CTB samples were prepared. After mixing, each batch of samples was compacted at hourly intervals up to 4 hours. The dry density and moisture content were determined according to ASTM D558. After compaction, samples were conditioned at moist condition till the age of testing. The unconfined compressive strength for the age of 7 and 28 days were determined according to ASTM D1633 (method A). According to the FAA (2014) requirements, the 7-day unconfined compressive strength shall be 2758 - 5516 kPa, and not exceeding 6895 kPa at 28 days age. Air temperature was also recorded as reference.

| Sieve Size | Allowable Passing Percentage |
|------------|-----------------------------|
| 50mm       | 100                         |
| 4.75mm     | 45 – 100                    |
| 2.0mm      | 37 – 80                     |
| 0.425mm    | 15 – 50                     |
| 0.18mm     | 0 – 25                      |

Table 1. Specification for Aggregate Gradation (FAA, 2014).
4. Results review and discussion

4.1. Results summary
Gradation analysis for the sand-granite aggregate mixture was conducted on every batch of CTB samples. The aggregate gradation results are shown in figure 2.

![Gradation Summary](image)

**Figure 2.** Gradation summary of aggregates.

After mixing the materials, the CTB samples were compacted at various time intervals ranging from 0hr (immediately after mixing) to 4hr at every 1hr interval. At each time interval, the dry density, moisture content and the unconfined compressive strength at 7 days and 28 days were determined. The average results based on 6 batches of samples are shown in table 2.

| Time interval between mixing and compaction | Air Temperature, °C | Average Moisture Content (%) | Average Dry Density (Mg/m³) | Average 7 day compressive strength (kPa) | Average 28 day compressive strength (kPa) |
|--------------------------------------------|---------------------|------------------------------|----------------------------|----------------------------------------|----------------------------------------|
| 0hr                                        | 28.4                | 7.04                         | 2.10                       | 5368                                   | 5925                                   |
| 1hr                                        | 29.8                | 6.81                         | 2.08                       | 4871                                   | 5449                                   |
| 2hr                                        | 30.3                | 6.56                         | 2.06                       | 4394                                   | 4984                                   |
| 3hr                                        | 31.1                | 6.26                         | 2.04                       | 3882                                   | 4362                                   |
| 4hr                                        | 31.2                | 6.00                         | 2.01                       | 3048                                   | 3442                                   |
4.2. Discussion of results

It is observed that CTB mixtures become drier as the compaction time (i.e. time between mixing and compaction) increases. As shown in figures 3 and 4, the moisture contents and dry densities of CTB decrease as the compaction time increases. It can be seen that dry density reduced approximately 0.02Mg/m$^3$ per hour. Based on the test results, the moisture content reduces about 1% and the dry density reduces 0.1Mg/m$^3$ after 4hrs.

![Figure 3](image3.png)

**Figure 3.** Average Moisture content of cement treated base mixtures.

![Figure 4](image4.png)

**Figure 4.** Average Dry Density of cement treated base mixtures.
As shown in figure 5, the 7-day compressive strength reduces as the compaction time increases. At 2 hours after mixing, the strength reduced to 4394 kPa which is still within the strength limit of 2758-5516 kPa.

![Unconfined Compressive Strength](image)

**Figure 5.** Average 7-day & 28-day strength of cement treated base mixtures.

Similarly, for the case of 28-day compressive strength, the strength also reduces as the compaction time increases. The average 28-day compressive strength reduced to 4984 kPa at 2hrs, 4362 kPa at 3hrs and 3442 kPa at 4hrs.

| Time between mixing and compaction | 1 hour | 2 hour | 3 hour | 4 hour |
|-----------------------------------|--------|--------|--------|--------|
| Loss in Moisture content, %       | 0.23   | 0.48   | 0.78   | 1.04   |
| Loss in Dry density, Mg/m³        | 0.02   | 0.04   | 0.06   | 0.09   |
| Loss in 7-day unconfined strength, kPa | 497    | 974    | 1486   | 2320   |
| Loss in 28-day unconfined strength, kPa | 476    | 942    | 1564   | 2484   |

Table 3 shows a summary of the average loss in performance properties of CTB mixtures by compaction time. According to the FAA specifications (2014), all placement, compaction, and finishing operations of the CTB shall be completed within two hours from the start of mixing. Based on the test results obtained from this study, the average loss of moisture is about 0.5% which is within the FAA (2014) moisture loss requirement of within ±2%. Nonetheless, even though the moisture loss is within the acceptable range, the dry density reduced by about 0.04Mg/m³ at 2 hours after mixing. In
the case of compressive strength, both the 7-day and 28-day strength reduced by about 1000 kPa at 2 hours after mixing.

5. Conclusions
Based on the test results obtained in this study, the following conclusions can be drawn:

a) Longer construction time significantly affects the performance properties of CTB even though all properties are still within the FAA requirements after 2 hours compaction time.

b) The 7-day and 28-day unconfined compressive strength were reduced by about 1000 kPa after 2 hours compaction time which is about 20% reduction.

c) The mix design should not be based on minimum required strength to avoid strength failure.

Further research is being carried out to investigate effects of climate (temperature and humidity) with compaction time on the performance of CTB.

References
[1] Federal Aviation Administration (FAA) Advisory Circular 150/5370-10G. 2014 Item P-304. Cement-Treated Base Course.
[2] Guthrie W. Spencer, Sebesta Stephen, Scullion Tom. 2002 Selecting optimum cement contents for stabilizing aggregate base materials, Texas Transportation Institute, Texas.
[3] Guthrie W. Spencer and Maile A. Rogers. 2010 Variability in construction of cement-treated base layers: material properties and contractor performance, Transportation Research Board 89th Annual Meeting, Washington D.C.
[4] Gregory E. Halsted, David R. Luhr and Wayne S. Adaska. 2006 Guide to cement-treated base (CTB), Portland Cement Association, Illinois, USA.
[5] Hossain M. Shabbir, Nair Harikrishnan, Ozyildirim H. Celik. 2017 Determination of mechanical properties of cement treated aggregate base, Virginia Transportation Research Council, Charlottesville, Virginia.
[6] Kevin J. Gaspard. 2000 Evaluation of cement treated base courses, Louisiana Department of Transportation and Development, Baton Rouge.
[7] Rasha. Abd Al-RedhaGhani. Mohammed A. Al-Jummaily, Ahlam K.R. Al-Zerjawi. 2018 Study of cement treated base aggregate properties for pavement structure, University of Kufa, Iraq.
[8] Yang Sheng Yeo, Peerapong Jitsangiam, Hamid Nikraz. 2011 Mix design of cementitious basecourse, Curtin University, Perth, Australia.