Lightweight concrete in cement-treated subbase construction

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Abstract. Following the development of transportation technology, steady road infrastructure is needed. The choice of construction type is a crucial point for the expected quality. Road construction consists of flexible and rigid pavement construction. Rigid pavement has higher durability and is produced from concrete, a strong, flexible, and fire-resistant material. Lightweight concrete, containing high amounts of pores, can be produced by using lightweight aggregate or a mixture of lightweight-coarse aggregate fulfilling the requirements for compressive and flexural strength. This study evaluated the compressive and flexural strength of lightweight concrete without coarse aggregate as a rigid pavement material. This study used specimens from type I Portland cement for compressive and flexural strength test, in 0.5 water-cement ratios and the specific gravity of 1.0. The result revealed a compressive strength value of 38.91 kg/cm² and a flexural strength value of 1.32 MPa. Based on the results obtained, it was concluded that lightweight concrete material fulfilled the general specification criteria for the compressive strength requirements of the cement-treated subbase (CTSB).

1. Introduction
Transportation is an activity to move people or goods from one place to another and is mainly purposed to connect humans to land use. Transportation has characteristics and attributes indicating its specific meaning and function. In this 20th century, the growth of transportation developed rapidly in line with the latest technological advances [1]. In accordance with the development of transportation technology, a steady road infrastructure is needed [2]. The development of road planning and construction is in line with the increasing need for speed, comfort, safety, and ease of traveling on land [3].

Road construction consists of flexible and rigid pavement construction. Flexible pavement is composed of asphalt concrete which is placed on top of a base or subbase layer supported by compacted subgrade. Rigid pavement generally consists of two layers, namely a concrete layer and a subbase [4]. In Indonesia, the use of flexible pavement structures is more dominant due to the lower cost. However, in terms of maintenance, flexible pavement structures require higher maintenance costs than rigid pavement. On the other hand, rigid pavement structures have higher durability compared to flexible pavements, so that high frequency loads, even of heavy vehicles, do not become a problem [5].

Based on this background, we conducted research on rigid pavement construction. Concrete, a construction material that has been commonly used, is the key substance required in the construction of rigid pavement. Various building constructions have used concrete as materials due to its high...
compressive strength, flexibility, fire resistance, affordability, and cost-effectiveness [6]. Lightweight concrete is one of the various types of concrete. It is a mixture of cement, water, and foam produced by the foam agents. Also being known as cellular or aerated concrete, this type of concrete is produced through certain techniques leading to the large amounts of pores contained. The pores, becoming a specific characteristic of lightweight concrete, are intentionally formed to reduce the weight of the concrete [7].

2. Literature review

2.1 Rigid pavement
The pavement type of choice varies based on traffic volume, design life, and condition of road foundation. Engineers should consider the lowest costs throughout the design life, in addition to the implementation effectiveness and limitations. For light to moderate traffic loads, flexible pavement is more suitable than rigid pavement. This can be seen especially in certain rural or urban areas where road construction is less disruptive to the traffic. Rigid pavements can be a cheaper option for urban roads with limited access for heavy vehicles. In a limited area, the implementation of rigid pavement will be easier and faster than that of flexible pavement [8].

2.2 Rigid pavement with cement-treated base (CTB)
For roads serving medium and heavy traffic, a CTB foundation layer is preferred than a grained foundation layer due to its cost-effectiveness. The CTB can economize the use of asphalt and grained materials and is less sensitive to water than grained foundation layers. It can be substituted by Lean Mix Concrete (LMC) that is easier to implement in narrow working areas such as pavement widening work or work in urban areas [8].

Overloaded vehicles are a real condition that must be anticipated. Such loads can cause premature cracking of the CTB layer. Therefore, CTB design is only based on the CTB stiffness modulus at the post-fatigue cracking stage without considering the age of pre-fatigue cracking [8]. The unconfined compressive strength requirements of the Cement Treated Base (CTB) and Cement Treated Subbase (CTSB) at the age of 7 (seven) days are 45 - 55 kg/cm² and 35 - 45 kg/cm², respectively [9]. The CTB construction requires a competent contractor with adequate equipment resources, as CTB pavements are only selected if the required resources are available [8].

2.3 Lightweight concrete
Based on SNI 03-3449-1994, lightweight structural concrete is a concrete that uses lightweight aggregate, or a mixture of lightweight-coarse aggregate and natural sand as a substitute for lightweight fine aggregate and meets the requirements for compressive and flexural strength with the maximum weight of 1850 kg/m³. The flexural strength of air-dry lightweight concrete ranges from 70% to 90%, compared to the general concrete of the same compressive strength. Nevertheless, if being exposed continuously to a certain level of moisture, these two types would have the same level of flexural strength [10].

The development of lightweight concrete at Universitas Syiah Kuala (USK) began in 2006. USK has been able to produce lightweight concrete with structural quality (compressive strength value > 17 mPa). Various qualified products using lightweight concrete as a material have been invented [11].

Lightweight concrete is classified into low density concrete (content weight less than 50 pcf (800 kg/m³)), medium strength concrete (content weight ranging from 60 - 80 pcf (960 - 1360 kg/m³) and compressive strength between 1000 - 2500 psi (6.89 - 17.23 MPa)) and structural concrete (content weight ranging from 90 - 120 pcf (1440 - 1920 kg/m³) and equal compressive strength to the general concrete) [12]. In general, concrete is obtained from a mixture of Portland cement, water and aggregate, while for lightweight concrete, the constituent materials depend on its type. Lightweight concrete is a mixture of cement, water, air, and foam produced from foam agents. Production of lightweight concretes is generally done by adding air bubbles into the concrete mixture or by using lightweight aggregates, such as clay and pumice [13].
2.4 Compressive and flexural strength

Compressive strength is an illustration of the concrete quality. According to SNI 03-1974-1990, concrete compressive strength is the amount of load per unit area that causes the concrete specimens to collapse when loaded with a certain compressive force generated by a compressive testing machine [14]. Flexural strength is the ability of concrete placed on two positions to withstand the force given in the direction perpendicular to the axis of the specimen until collapsed which is stated in Mega Pascal (MPa) force per unit area. The concrete flexural strength affects its ability to overcome the initial cracks before being loaded [15].

3. Materials and methods

3.1 Materials

The manufacture of the cylindrical specimens with a diameter of 15 cm and a height of 30 cm was intended for compressive strength test, while another specimen in the form of blocks with a size of 15 cm x 15 cm x 60 cm was used for the flexural strength test. The water-cement ratio was 0.5, and the specific gravity was 1.0. The cement used was type I Portland cement, as shown in Figure 1. The equipment used included a press loading machine with a capacity of 100 TF, balance, filter, concrete mixer, and foam generator.

![Type I Portland cement](image)

**Figure 1.** Type I Portland cement.

3.2 Methods

3.2.1. Specimen manufacture and maintenance. The specimen manufacture, listed in Table 1, was carried out at the Construction and Building Materials Laboratory of the Civil Engineering Department of Unsyiah in the following procedures:

- Preparation and measure of the materials according to the predetermined proportion of the mixture.
- Addition of water and cement into the foam produced by the generator in the concrete mixer until well blended.
- Adjustment of the concrete mixture on the mold and formation of the concrete cast.
- Treatment of the concrete was carried out after hardened.
- Removal of the concrete cast from the mold to be put under immersion.

| Test               | Specimen                        | Quantity |
|--------------------|---------------------------------|----------|
| Compressive Strength| Cylinder 15 cm x 30 cm          | 3        |
| Flexural Strength  | Block 15 cm x 15 cm x 60 cm     | 3        |
| **Total**          |                                 | **6**    |

**Table 1.** The lists of specimen manufacture for each test.
3.2.2. Compressive strength test. The cylinder specimens were tested at the age of 7 (seven) days of concrete after immersion. Before doing the tests, it was confirmed that the specimens were dried, weighed and measured. The test was carried out by giving loads until the specimens were destroyed. The compressive strength test equipment is displayed by Figure 2.

![Figure 2. Compressive strength test equipment.](image)

3.2.3. Flexural strength test. The block specimens were tested at the age of 7 (seven) days of concrete after immersion. Before doing the tests, it was confirmed that the specimens were dried, weighed and measured. The test was carried out by giving loads until the specimens were destroyed. The flexural strength test equipment is shown in Figure 3.

![Figure 3. Flexural strength test equipment.](image)
4. Results
The compression and flexural strength value obtained are shown in Table 2 and Table 3. Table 2 shows the average value of the compressive strength of lightweight concrete at the age of 7 (seven) days was 38.91 kg/cm², and the average value of flexural strength obtained at the age of 7 (seven) days was 1.32 MPa. Based on the literature, the criteria for the unconfined compressive strength of CTSB at the age of 7 (seven) days is 35 - 45 kg/cm² [9]. These results indicate that the quality of lightweight concrete tested at the age of 7 (seven) days has met the compressive strength requirements. In normal and lightweight concrete, higher concrete age increases the concrete quality. Likewise, the flexural strength value is also directly proportional to the concrete age [16]. These results were considered interesting because the specific gravity of lightweight concrete tested for use in a pavement layer was very small compared to the specific gravity of normal concrete which reaches 2.4. This was very significant to the reduction of concrete own weight in the road foundation.

Table 2. The compression strength values.

| Specimen | Weight (kg) | Dimension | Force (Ton) | Compression Strength (kg/cm²) |
|----------|-------------|-----------|-------------|------------------------------|
|          |             | Height (mm) | Diameter (mm) | Area (mm²) |                  | | Unit | Average* |
| 1        | 5.58        | 301.00     | 149.40      | 17521.48 | 6.00 | 58.86 | 3.36 | 34.26 | 38.91 |
| 2        | 5.38        | 302.00     | 150.20      | 17709.63 | 7.00 | 68.67 | 3.88 | 39.56 | ± 4.37 |
| 3        | 5.32        | 305.00     | 149.20      | 17474.60 | 7.50 | 73.58 | 4.21 | 42.93 |          |

* The data is presented as mean ± SD.

Table 3. The flexural strength values.

| Specimen | Weight (kg) | Dimension | Maximum Load (tf) | Flexural Strength (MPa) |
|----------|-------------|-----------|-------------------|-------------------------|
|          |             | Length (mm) | Width (mm) | Height (mm) | l (mm) |                  |          |
| 1        | 11.84       | 522.00     | 150.00     | 150.00     | 450.00 | 0.75  | 7.36 | 0.98 | 1.32 |
| 2        | 13.96       | 601.00     | 150.00     | 149.00     | 450.00 | 0.75  | 7.36 | 0.99 | ± 0.58 |
| 3        | 14.16       | 600.00     | 148.00     | 150.00     | 450.00 | 0.82  | 8.04 | 1.09 |          |

* The data is presented as mean ± SD.

5. Conclusions
Based on the results obtained, it was concluded that lightweight concrete material fulfilled the general specification criteria for the compressive strength requirements of CTSB. As in normal concrete, the quality of lightweight concrete without coarse aggregate is directly proportional to the concrete age. Therefore, lightweight concrete can be used as a material in rigid pavement. The utilization of this material in pavement construction can be considered to improve the pavement stability. We propose that further research is required to identify the effect of substituting lightweight concrete with alternative materials in order to reduce the initial cost of rigid pavement.

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