Effect of Moisture Content on the Compressive strength of a Local Rammed Earth Construction Material

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***Abstract*— Finding sustainable and economical materials for building construction is a vital topic recently due to the negative effects of some current construction materials on the environment and also its relatively high cost. Local materials can be considered as a suitable alternative for building construction materials to minimize the environmental impacts. For example, rammed earth construction type uses local materials which typically consist of a mixture of gravel, sand, clay, and silt. Cement can be added with low fractions as a stabilizer and to improve the mechanical properties of rammed earth, such as compressive strength. This study focuses on assessing the moisture content effect on the compressive strength of the cement stabilized local rammed earth materials. A number of samples with various moisture content, i.e. 4%, 6%, 10%, and 14% were established and examined using a universal test machine in this study. The moisture content is found to significantly affect the compressive strength of the stabilized rammed earth local materials. Samples with 10% moisture content reached the highest compressive strength (average is 4 MPa) compared with others. Samples with 4% moisture content have the least compressive strength, i.e. average is 1.97 MPa.**

***Index Terms*—rammed earth, alternative construction materials, cement stabilized rammed earth, sustainable building material**

I. Introduction

The world tends to try to build the earth and live on it without negatively affecting the nature, whether on the ground, the weather, or organisms. For thousands of years, people have been using natural materials fairly well such as soil in construction, especially in dry areas. In many regions of the Middle East in general and the Kingdom of Saudi Arabia in particular, there are different models of construction by using soil, and that reflects the cultural identity and the unique construction style of each region. In Najed region, there are huge amounts of soil, which motivates us to utilize and exploit these natural materials to develop effective, sustainable, low-cost construction materials. Rammed earth wall is one of the construction methods that have been used in many countries of the world, such as China, Australia, and some countries in Europe, North Africa, and North and South America from many years ago, and this method mainly depends on in site soil. The Construction using rammed earth materials, used in building walls, is developed by mixing the in-site soil, gravel, and clay at varying rates with water in a gradual way until it is wet and not reaching the level of liquidity. Then, the wall formwork is made and the mixture will be placed in layers with a thickness of about 20 cm, then compact each layer with a specific weight and number of compacts. After a while, the wall framework will be unfolded. However, rammed earth materials are vulnerable in durability and weak in compressive strength compared with other construction materials. Thus, cement is added to stabilize the walls and reduce renovation [1-3]. Natural and synthetic fibers are also included in the rammed earth materials to improve their mechanical characteristics [4, 5]. The scope of adding and modifying the materials of this construction method remains related to each region according to the available natural materials and then studying the structural properties, making the necessary tests, and assessing the mechanical properties of the material. There are some codes that exist for rammed earth such as IS: 2110 Code of practice for in situ construction of walls in buildings with soil–cement, Bureau of Indian Standards, New Delhi, India, and NZS: 4297, NZS: 4298, and NZS: 4299 codes from New Zealand provide specifications for the construction of rammed earth apart from other earth building methods [6]. Thus, this study will characterize the mechanical properties of the local soils available in Qassim region in Saudi Arabia, so to be used as material compositions of the rammed earth. The work focuses on examining on compressive strength of the rammed earth material while varying the percentages of moisture content.

II. Literature Review

Reviews of some papers on rammed earth construction are highlighted below. There are many studies and investigations on soil stabilization as applicable to the construction.

Various studies have drawn limitations for the composition of rammed earth materials to maintain their mechanical properties. Maniatidis and Walker (2003) [7]

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reviewed the recommended soil composition in cement stabilized rammed earth as proposed by various authors as follow: 70 % for sand & gravel and 30% for clay & silt [8-10], 75 % for sand & gravel and 25% for clay & silt [11-13], 60 % for sand & gravel and 40% for clay & silt [9], 65 % for sand & gravel and 35% for clay & silt [14] also Maniatidis and Walker (2003) [7] showed that the soil tends to contain a higher proportion of sand and gravel, and a lower fines content in cement stabilized rammed earth.

Bahar et al. (2004) [15] made an experimental study of soil with a granular gradation and chemical composition and then adding cement, to investigate the method of stabilizing the soil by mechanical or chemical means such as cement. The effect of each method on shrinkage, compressive strength, tensile strength, and water resistance was examined. A combination of mechanical and chemical stabilization was found to result in good compressive strength and durability. The study also indicated that better performance for dry samples than immersed in water samples.

Anysz and Narloch (2019) [3] examined the compressive strength of a set of 373 samples. The cement content in the samples of cement stabilized rammed earth varied from 3% to 10% and their moisture content from 6% to 14%. The study showed that the mean compressive strength of a cube mold was 6.00 MPa with a standard deviation of 2.093 MPa and the compressive strength varied from 2.400 to 13.011 MPa, and at the highest compression strength the moisture content was 8% and Cement content of 9%, wherefore the compressive strength and the cement added is positively (but not strongly) correlated.

Narloch et al. (2015) [16] studied two soil mixtures where each mixture contained 30% of loam and 70% aggregate. The mixtures have a different granular composition of the aggregate, the first mixture contained only a sand fraction and had higher optimum moisture content. The second mixture contained 40% of the sand fraction and 30% of the 2-4mm gravel fraction. The results of laboratory testing point to the fact that the content of the gravel fractions increases the flexural tensile strength. The average value of the flexural tensile strength of the samples from the second mixture was 137% bigger than the average value acquired from the first mixture. It has to be noted that the difference in results may be due to the higher moisture content of the first mixture. One of the problems related to rammed earth material is the water sensibility as in general these materials are very sensitive to water when the surface is exposed to different ambient conditions.

III. Objectives of Study

Additional studies are required to address the effect of saturation and density on mechanical properties of the stabilized rammed earth local materials in Saudi Arabia. The local rammed earth materials that were used in this study were collected from the southeast of the Qassim region in Saudi Arabia. This study aims to examine the effect of various ranges of moisture content on the compressive strength of the collected stabilized rammed earth materials.

IV. Methodology

A. Materials

A stabilized rammed earth mixture typically consists of sand, gravel, and clay as shown in Fig. 1. Sand and clay were provided from the available areas in the southeast of the Qassim region in Saudi Arabia. A type I Portland cement was also added to the mixture, which complies with the Gulf and Saudi standards No. SASO/GSO 1914 type I – ASTM C 150 Type I.

Figure 1. Sand, gravel and clay used to make specimens.

The mixture was formed from 50% sand (0.1 to 0.5 mm), 30% gravel (5 to 10 mm), 20% clay (0.005 to 0.05 mm), and then 9% cement was added by weight. Water was added based on the required moisture content for each mixture. For example, the mixture has 10% of the moisture content indicates that the weight of the added water to the mixture equals to 10% of the total weight of the rammed earth materials (i.e. total weight of sand, gravel, and clay) to the mixture.

B. Used Equipment'S

A cylindrical mold with a diameter of 100 mm and a height of 200 mm was selected to determine the compressive strength following the ASTM C39 standard [17]. Molds used in preparing the samples are shown in Fig. 2. The mixtures were filled on layers where each layer range from 3 to 3.5 cm. The ramming process is done manually 25 times for each layer using a rambler that has a 2.5 Kg weight and dropped from a 35 cm height.

The specimens to be tested were extracted from the mold after 24 hours. Then they were cured for 7days at room temperature. The specimens were tested using a universal test machine as shown in Fig. 3 with a speed rate of 1 mm/min. Fig. 4, shows a specimen under the compression test and after the test

Figure 2. The mold used in preparing the specimens and the rambler that was tamping the mixture.

Figure 3. The universal testing machine.

Figure 4. A cylindrical specimen under the test and after the test.

V. RESULTS AND DISCUSSIONS

The results of samples with different percentages of moisture content (i.e. 4%, 6%, 10%, and 14%) are shown in Fig. 5. The effect of moisture content becomes clear, as the compressive strength increases with increasing moisture content until 10% of moisture content is reached. After that, the compressive strength begins to decrease with the increase of moisture content. Specimens with a moisture content of 4% closer to being dry and possess the lowest compressive strength with an average of 1.97 MPa. The sample was not cohesive during the mix and after the sample unfolded which may contribute to the low compressive strength value. Specimens with a moisture content of 6% are wetter and more cohesive than the specimens with a moisture content of 4%, and they have reached an average compressive strength of 2.96 MPa. The samples with a moisture content of 10% were compliant and easy to compact and it reaches the highest compressive strength with an average of 4 MPa, hence, selected as the optimum mixtures. After that, specimens with a moisture content of 14%, which tended to be viscous and fluid, had a decrease in their compressive strength, where the average was 3.22 MPa.

The determined optimum moisture content mixture will be selected to perform further tests on the mechanical properties of stabilized rammed earth (i.e. compressive and tensile tests) as well as including various quantities of fibers (i.e.0.2%, 0.5%, and 1%) and types that available and suitable for the local environment (i.e. steel, polypropylene, and wood straw).

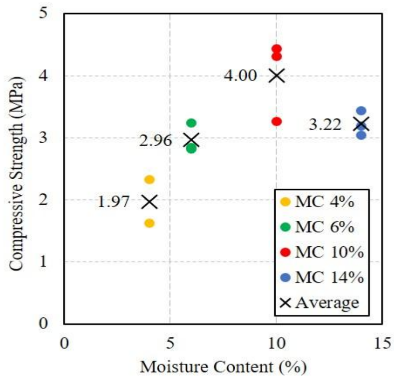

Figure 5. Compressive strength of stabilized rammed earth samples with various moisture content.

VI. Conclusion

This study evaluates the compressive strength of a local stabilized rammed earth materials with various of moisture content (i.e. 4%, 6%, 10% and 14%). The results consider preliminary evaluations for a broader study that aims to provide an alternative local construction material that is sustainable and with less impact on environment. The compressive strength results indicate that the sample with a moisture content of 10% possesses the highest value and thus selected as the optimum mixture. The study will be extended to further examined the mechanical properties (i.e. compressive and tensile tests) of the optimum mixture stabilized rammed earth with the inclusion of various fibers types and quantities.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Omar Alawad formulated the research and reviewed the literature related to the research, Omar Al-Sudays collected and prepared the necessary materials and tools for making samples, then making them, testing them, and analyzing the data; all authors had approved the final version.

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