Advanced and Sustainable Technologies
ASET
E-ISSN 2976-2294
Volume 3, No 1, June 2024 [1-12]

Principle of Common Lab and In-Situ Testing With the Quality Control and the Case Studies

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Received 12 July 2023, Revised 16 August 2023, Accepted 23 August 2023

ABSTRACT

Testing building materials is essential for ensuring quality control in the construction field. In order to meet the necessary standards, codes, and specifications, it should adhere to the rules in the appropriate way. Soil, aggregate, and concrete are typically the materials tested. Aggregate testing, which is covered by BS 812, may also be tested in accordance with BS 1377, which regulates soil testing, to determine the particle size distribution. In accordance with the size of the soil, BS 1377 also provides standard guidelines on the test procedure for Proctor compaction. The Archimedes principle is used to determine the density by measuring the displacement of water or a related material, such as paraffin oil or sand. Moreover, the determination of the compressive strength of the concrete is regulated by BS EN 12390. The sampling procedure, standard procedure of the Proctor compaction test, visual evaluation of the compressive strength test failure modes, and the in-situ core should all be examined as described in this paper in order to guarantee the testing's high quality. The last section includes four common case studies in construction connected by the faulty cube-making process, the inconsistent compressive strength result, and the lack of coordination of construction activities. In conclusion, construction material testing is an integral part of quality assurance in construction, but it should be conducted in accordance with the standards to ensure that the materials have the necessary characteristics and properties to perform as intended.

Keywords: Testing, building materials, standard, quality control, case studies.

1. INTRODUCTION

Testing of construction materials is necessary to ensure their quality and suitability for various construction applications [1]. A wide range of materials are used in construction, including soil, aggregate, fresh concrete, hardened concrete, steel, brick, and asphalt mixtures. Construction materials can be assessed for their characteristics, performance, and compliance with specific requirements and guidelines using a variety of tests.

Material testing enables the detection of any discrepancies, flaws, or variations in the characteristics of building materials. Early detection of potential problems makes it possible to take corrective action before construction even starts, lowering the possibility of structural failures or performance issues. Furthermore, in terms of safety considerations, making sure construction materials are of a high enough quality to identify any flaws or potential hazards that could jeopardize the structural integrity of the project or pose risks during its construction or service life is essential for maintaining the safety of structures and the people who use them. Cost

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is another important consideration before the construction project is started. Thus, by performing material testing, potential problems can be identified early, and the likelihood of expensive rework or repairs is decreased. It enables the selection of appropriate materials based on their performance qualities, preventing the use of inferior or inappropriate materials that might result in long-term cost increases. Last but not least, time is also crucial for the construction project, which may impact the contractor's profit. Therefore, material testing ensures that building materials comply with all legal and regulatory requirements, preventing legal issues or delaying the approval of projects.

Overall, testing of building materials is a crucial aspect of quality control in construction. It aids in ensuring that materials used in construction projects adhere to the necessary standards, carry out as intended, and enhance the overall quality, durability, and safety of the built structures.

2. COMMON TEST METHOD

2.1 Particle size distribution

BS 1377 [2] deals with the materials less than 10% of the material retained on a 37.5 mm test sieve, which is categorized as soil, while BS 812 [3] regulates aggregates and some of the materials, which include soils with more than 10% of the material retained on a 37.5 mm test sieve. However, particle size distribution can still be tested according to BS 1377, even in soil that does not meet the specific material retained percentage on a specific test sieve. In addition, if there is a particle size smaller than 63 micrometers, the moisture content and plasticity tests can also be examined using the test methods of this standard.

Generally, particle size distribution is determined according to BS 1377-2:1990 [4] by grading and the sedimentation by the hydrometer method, which is suitable as more than 10 % passing the 63-micrometer sieve, as shown in Figure 1. Both methods are able to determine the particle size distribution, from the size of gobbles to clay. The sedimentation by the hydrometer method can determine the size of silt and clay, while the determination of particle size distribution by sieving can determine the size of gobbles, gravel and sand. The minimum mass of the sample for these two methods is obtained based on the type of soil and prepared by wet sieving through the 63-micrometer test sieve, whereby the passing material is used for sedimentation test by the hydrometer while the retained materials are oven-dried, dry sieving and the material passing through the 63 micrometer test sieve should be collect and added to the passing material from the wet sieve as the total sample for the sedimentation test before starting. The invalid sedimentation by the hydrometer method can be checked by the initial equivalent particle diameter, which must be started at 0.063mm. If not, it should be redone. This is because the smallest size for determining the particle size distribution is 0.063mm. Hence, it should be continuous and start at 0.063 mm.

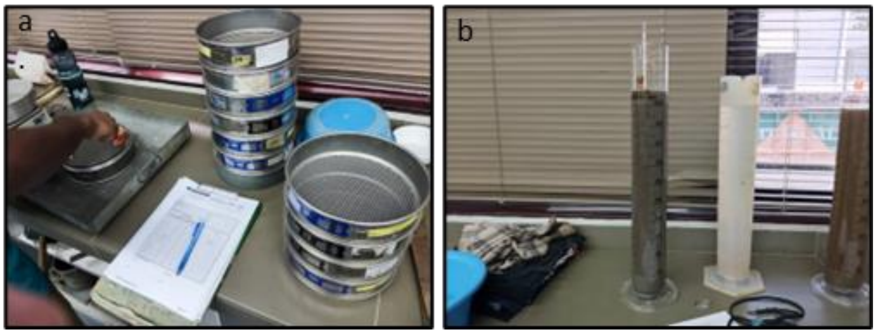

Figure 1: (a) dry sieving and (b) sedimentation by hydrometer method.

Furthermore, the determination of sand equivalent value of soils and fine aggregates, as shown in Figure 2 according to ASTM D 2419-14 [5], serves as a rapid field correlation test. The purpose of this test method is to indicate the relative proportions of clay size in fine aggregates. A sample of fine aggregate is mixed with a calcium chloride, a flocculating solution in a graduated cylinder and agitated to loosen clayey fines present in and coat the aggregate. After a settling period, the cylinder height of suspended clay and settled sand is measured, and the sand equivalent value is computed as the ratio of the sand to clay height readings, expressed as a percentage.

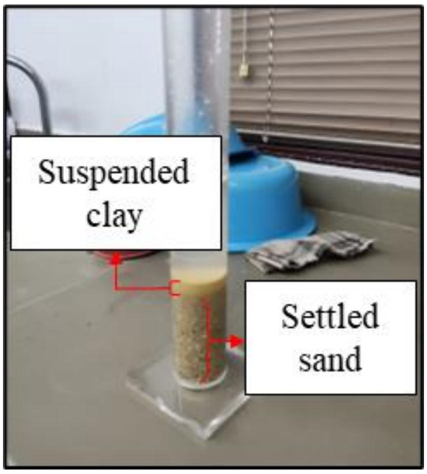

Figure 2: Separation layer of suspended clay and settled sand.

Last but not least, BS EN 933-1: 2012 [6] is the international standard used to determine the particle size distribution of aggregates. To acquire the necessary number of specimens, samples must be decreased in accordance with BS EN 932-1 by riffling, as shown in Figure 3 [7]. The specimen needs to be dried at (110 5) ^{o}C until it reaches a consistent mass. The material is then washed through a 63-micron screen after soaking in water. In order to protect the delicate mesh that it is composed of, a 2 mm sieve is used as a protection sieve on top. The remainder kept on the 0,063 mm sieve is then oven-dried to a constant mass at (110 + 5^{o}C), weighed and sieved to determine particle size distribution.

Figure 3: Riffling by sample splitter.

2.2 Proctor compaction

Basically, in this test, a compaction mould of 1 L internal volume is used for soil in which all particles pass a 20 mm test sieve, while CBR is used for a maximum of 10% and 30% of the number of particles up to 37.5 mm and 20.0 mm, respectively. Therefore, the sample should be sieved first to determine the approximate percentages by mass of particles in the soil sample passing the 20 mm and 37.5 mm test sieves to select the appropriate mould. Besides, for soils containing particles not susceptible to crushing, one sample only is required for the test, and it can be used several times after progressively increasing the amount of water. For soils containing particles that are susceptible to crushing, such as soft limestone and sandstone, it is necessary to prepare separate batches of soil with different moisture contents, each for compacting once only; otherwise the characteristics of the material will progressively change after each application of compaction. According to BS 1377-4: 1990, the quantity of the specimen for the compaction based on different kinds of mould used and soil susceptibility to crushing is shown in Table 1. [8]. Generally, the proctor compaction test with the 1-liter mould and 4.5 kg Rammer method is applicable, especially at roadwork, while the proctor compaction test with the 1-liter mould and 2.5 kg Rammer method according to the specification of earth fill dam construction where the backfill material at the site of the dam construction is a soft material with about 24–27% natural moisture content.

Table 1: Minimum mass of specimen for testing.

Type of mould	Soil particles susceptible to crushing	Minimum mass of prepared soil required (kg)
1 L	No	6
	Yes	15
CBR	No	15
	Yes	40

2.3 Determination of density of materials

Basically, the determination of the density of the material is based on the Archimedes principle, which states that the buoyant force acting on a submerged object is equal to the weight of the fluid displaced by the object. The volume of an object is determined by measuring the buoyant force acting on it [9]. The tests related to the Archimedes principle are shown in Table 2.

Based on Table 2, No.14 test, the field density test, also known as the sand replacement method, is a geotechnical testing procedure used to determine the in-situ density of soil. While it is not directly based on the Archimedes principle, there are some similarities in terms of the principles involved. The sand replacement method relies on the principle of volume displacement. In this test, a hole is excavated in the ground and filled with a known volume of sand. The volume of sand used is measured precisely. After filling the hole, the weight of the excavated soil is determined. By knowing the weight of the soil and the volume of the hole, the in-situ density of the soil can be calculated. Although the Archimedes principle deals with buoyancy and the sand replacement method does not involve the direct measurement of buoyant forces, both principles relate to the displacement of a material to determine its properties. In addition, in the case of coarse and very coarse-grained- soil, the In-Situ Density by water Replacement Method, as shown in the No.13 test, is used when the other methods for determining the field density are unsuitable because the volume excavated would be unrepresentative.

Table 2: Summary of determination of density of materials.

No.	Tests	Test method	Fluid/ Material displacement
1.	Determination of The Particle Density of Soil by Small Pyknometer Method	BS 1377: Pt. 2 : 1990 : Clause 8.2 [4]	Water
2.	Determination of The Particle Density of Soil by Small Pyknometer Method	BS 1377 : Pt. 2 : 1990 : Clause 8.3 [4]	Water
3.	Determination of The Particle Density of Soil by Large Pyknometer	BS 1377 : Pt. 2 : 1990 : Clause 8.4 [4]	Water

Table 2: (continued)

No.	Tests	Test method	Fluid/ Material displacement
4.	Determination of Density of soil by Immersion in Water	BS 1377 : Part 2 : 1990 : Method 7.3 [4]	Water
5.	Determination of Density of Cement	BS EN 196-6:2010 [10]	Paraffin oil
6.	Density, Absorption and Voids in Hardened Concrete	ASTM C642-2013 [11]	Water
7.	Determination of The Particle Density - Fluid Pycnometer Method	BS EN ISO 17892 - 3: 2015 - Method 5.1 [12]	Water
8.	Bulk Specific Gravity and Density of Non-Absorptive Compacted Asphalt Mixtures	ASTM D2726/D2726M – 17 [13]	Water
9.	Determination of Relative Density (Specific Gravity) and Absorption of Coarse Aggregate	ASTM C 127 – 15 [14]	Water
10.	Determination of Particle Density and Water Absorption - Fine Aggregate (Pyknometer Method)	BS EN 1097-6: 2013 Clause 9 [15]	Water
11.	Determination of Particle Density and Water Absorption - Coarse Aggregate by Wire Basket Method	BS EN 1097-6 : 2013 Clause 7 [15]	Water
12.	Determination of Density and Compaction of Bituminous Mixtures	BS 598 : Part 104 : 2005 [16]	Water
13.	Determination of In-Situ Density of coarse and very coarse grained- Soil by water Replacement Method	BS 1377 : Pt. 9 : 1990 Method 2.1 / 2.2 [17]	Water
14.	Determination of In-Situ Density of fine, medium coarse grained- Soil by Sand Replacement Method	BS 1377 : Pt. 9 : 1990 Method 2.3 [17]	Sand

2.4 Determination of density and compressive strength of concrete

The method of making the cubes will affect the compressive strength of the cubes, so the methods of making them should be based on the standard BS EN 12390-2 [18]. Besides, the auxiliary platens are used in compressive strength test machines to ensure that the specimen being tested is loaded uniformly and without any bending or tilting during the test. These plates provide additional support to the specimen and help to distribute the load evenly across the surface of the specimen. In a compressive strength test, the specimen is placed between two platens - the upper and lower platens - and a compressive force is applied to the specimen until it fails. The auxiliary platens are positioned between the upper platen and the specimen and between the lower platen and the specimen. Therefore, it ensures that the test results are accurate, reliable, and consistent. Additionally, spacing blocks may be used if there is a requirement to reduce the distance between the machine platens. In addition, for stability reasons, the total number of spacing blocks shall not exceed four based on BS EN 12390 4:2019 [19].

Besides, according to the testing date after casting, the concrete specimens are taken out of the water, the extra moisture on the surface of the specimens is wiped off, the mass and dimension of the specimens are determined, and the compressive strength test is conducted to determine the maximum load that can be sustained by the specimens [19]. The density and compressive strength of the specimens will be computed based on the measurement of their mass and dimension. In the case of casting samples in cube mould, the height of the cubes in the mould will be slightly larger than the width, and the length of the mould, which is due to the top surface, is not restrained by the mould. Generally, the specimen that is cube-shaped in 100mm is the grout sample, while the specimen that is cube-shaped in 150mm is the conventional concrete or shotcrete sample. For the core specimen, the diameter should be cut at a height ratio of 1:1 with the dimensions of 100mm and capped with the material for compressive strength determination. Basically, in terms of 150 mm cube, the density of the grout, shotcrete, and conventional concrete is around 1990 kg/m^3, 2200 kg/ m^3 and 2400 kg/ m^3, respectively.

3. QUALITY CONTROL

3.1 Sampling

According to BS 1377-1: 1990 [2], the total mass of sample necessary for testing after assessment sieving depends on the soil category and the tests to be performed to ensure a representative sample. The total sample mass required for testing after assessment sieving is 500 g for fine-grained soil, 5 kg for medium-grained soil, and 30 kg for coarse-grained soil. The greater the sample size, the greater the mass of the sample required to represent the sample. According to BS 812-102:1989 [20], samples should be taken from diverse portions of the batch to represent the average quality. As sampling from aggregate stockpiles, the surface material should be removed at least 150 mm below the surface and reduced utilizing a divider to the required specimen mass.

While regarding the fresh concrete sample was taken as it was removed from the truck mixer, as shown in Figure 4. It is preferable to disregard the first and last sentences [21]. This will result in a consistent sample. It's possible that the start and end portions of the concrete stream will not have the ideal consistency as a result of deviations in the mixing process, settling during transport, or temperature changes. Additionally, segregation, in which the cement paste and coarse aggregates separate during the delivery and pouring procedures, is a potential problem with concrete. The beginning and last portions of the concrete stream are also more likely to come into touch with impurities like grit, debris, or water from the leftover content of the mixer.

Figure 4: Sampling of fresh concrete for slump testing and cube making.

3.2 Failure modes of compressive strength test

According to BS EN 12390-3:2019 [22], the failure modes of the concrete, cylinder, and core specimens should be remarked as satisfactory or unsatisfactory at the completion of the testing. In a compressive strength test, for example, only cracks parallel to the force should be present. An unsatisfactory failure occurs when an uneven stress distribution and concentration within the specimen reduces the measured bearing load, which can be indicated by the tensile crack or crack on the load-applied surface [23 & 24]. As a result, before applying a load to the concrete sample, the surface should be guaranteed to be flat and perpendicular to the force applied. As a result, the load-bearing surfaces of cube specimens must be moulded, whereas cylinder and core specimens must be ground or capped [25]. Furthermore, preparation capping for the masonry unit for compressive strength test according to BS EN 772-1:2011 [26] is required.

For the capping material, the capping mix designs should be at least as strong as the concrete specimen at the time of the test to avoid failure before reaching the maximum load. This is due to the objective of providing a smooth bearing surface for loading so that the load can spread equally over the specimen without tensile cracking in order to provide a consistent and accurate result. Before capping, ensure that the specimen being capped has a moist, clean surface and that any loose particles have been removed. Furthermore, the caps must be as thin as feasible and no thicker than 5 mm. The specimen is clamped with zinc so that the upper edge is horizontal and only extends slightly over the highest part of the concrete surface. The capping material is filled into the collar until it produces a convex surface over the collar's edge. The glass capping plate is then forced into the capping material with a rotational motion until it is completely in contact with the collar's edge. The operations are repeated for the other end of the core, and a weight is placed on top of the glass plate, as shown in Figure 5. Last but not least, the specimen should be placed as soon as possible in moist air with a relative humidity of less than 95% and at a temperature of 20 to 5 °C [22].

Figure 5: Fresh finished capped core samples.

3.3 Assessment of the In-situ core

The excess voidage on the surface of the core is assessed, as shown in Figure 6, by comparing the number and size of the voids revealed on the drilled surface of the air-dry core to those shown in BS EN 12504-1:2019 Figure NA.1(a) to (e) [27]. There will always be some entrapped air in the standard test specimen, generally 0.5% for concrete, and the excess voidage should be zero. This additional voidage will have reduced the measured core strength of the concrete relative to a normal test specimen, which is an indicator of the resulting compressive strength of concrete. Besides, the compressive strength of the core is to be corrected to the in-situ cube strength with the core dimension correction factor according to the BS EN 13791-2007 [28] and the reinforcement bar correction factor according to the CSTR 11-1987 [29] which will reduce the strength of a core.

Figure 6: Voidage of the core.

3.4 Proctor compaction test

The purpose of proctor compaction is to compact a soil specimen in layers using a standard compaction effort (4.5 kg rammer) to produce a maximum dry density and optimum moisture content by reducing the air void that occupies the void space between the soil grain to a minimum and constant [30 & 31]. According to BS 1377-4: 1990 [8], at least five determinations must be performed. The moisture contents must be chosen so that the optimal moisture content, at which maximum dry density occurs, is towards the centre of the range. As a result, when the wet sample has been air dried to a particular low moisture content, it can be double-checked by recognizing the moisture content using a microwave to obtain the moisture content quickly. Furthermore, the huge lump sample must be broken up into small pieces so the entire sample can be air-dried uniformly. To prevent stratification, each compacted layer should be scratched with a spatula before adding the next layer [32]. If the fourth layer is extremely close to the top of the mould, it can usually be scraped more deeply. When the new layer is not effectively attached to the preceding layer, a separation plane, which is a weak interface between the two layers, might form. The separation plane can form as a result of a lack of adhesion between the two layers, resulting in non-uniform compaction. As a result, the dry density of the soil specimen may be lower than expected. This occurs because the separation plane limits the effective stress transmission between the two layers, allowing soil particles to move more freely and settle less densely than if the layers were strongly bonded. In other words, if there is a separation plane, the soil particles in the upper layer will not compact as firmly as they should, resulting in a lower dry density for the soil specimen than if the layers were well bonded. As a result, in the Proctor compaction test, obtaining a consistent and well-compacted soil specimen is critical. The air void line on the graph of the relationship between MDD and OMC can be used to determine the authenticity of the findings. The OMC and wet density will generally be between the zero and 5% air void lines.

Besides, there is a reversed method of doing the proctor compaction test, which is done from wet to dry, as the proctor compaction test can be performed directly on the natural state of the soil sample without air drying for the first recording, in which the natural moisture of the soil sample will be higher than the OMC and fall in the wet optimum between the MDD and the lowest dry density. Hence, the test can be finished quickly instead of commencing the test air drying one day. Alternative proctor compaction tests are usually used here to reduce this kind of mistake of improper mixing that results in invalid results. The critical thing is to estimate the duration of drying under sunlight so that the water and moisture in the soil samples are distributed evenly. The sunlight at about 12 p.m. is very hot, so it should be put aside for a while for the next point of testing.

Furthermore, for Proctor compaction with a 2.5 kg rammer, the optimum moisture content is higher, while the dry mass density is lower if compared to Proctor compaction with a 4.5 kg rammer. This is because the degree of compaction is lighter in Proctor compaction with a 2.5 kg rammer, which needs much more water to lubricate the soil to be compacted and reduce the air void percentage. This method is suitable for constructing earthfill dams with soft materials rich in clay [33].

4. CASE STUDIES

4.1 Failure of meeting characteristic strength at 28 days

There is a problem with the concrete cube failing to meet the minimum characteristic strength at 28 days, despite the strength requirement being met at 7 days after casting. This is because the concrete cube specimen was exposed to sunshine for a few days before being demoulded and placed in water after hardening. The hydration process between water and cement occurs throughout the curing phase, resulting in the hardening and strength development of the concrete [34]. Curing with water helps keep the surroundings moist, ensuring enough water is accessible for the continuous hydration process. This improves the overall strength and durability of the concrete. Without proper curing, the concrete surface might soon dry out owing to evaporation, resulting in shrinkage, cracking, and lower strength [35].

4.2 High water-to-cement ratio

There are several voids on the surface of the concrete cube specimens. This could be because of the high water-to-cement ratio. Excess water results in a higher water-to-cement ratio. This increasing ratio indicates that the available water exceeds the amount needed to hydrate the cement particles completely. Excess water fills the cavities between the cement particles and generates additional holes or pores within the concrete that are not chemically consumed during the hydration process. These extra voids decrease the hardened concrete's density while increasing its porosity. Increased porosity means more interconnected pores or channels within the concrete structure, allowing moisture and other things to pass through. This higher permeability can result in lower durability and resistance to chemical attack. Furthermore, voids or pores disrupt the continuity and regularity of the cementitious matrix, limiting effective load transfer and jeopardizing the concrete's mechanical qualities [36].

4.3 Failure of requirement compaction

There is a field density test on the base course of the main access road on the right bank, where the material is river sand. Based on the result of the bulk density, the relative compaction is just 82% and has 4 %C of moisture content, which fails to meet the requirement for compactions, which is 95% as according to the result of proctor compaction, the optimum moisture is 8.5% with an MDD of 2.040 Mg/m^3. Therefore, the filling materials should be conditioned before compacting by drying or wetting procedures to bring them within the specified moisture content range. In addition, before the next placement of the filling material on the compacted layers, it should be scratched to provide satisfactory bonding as simulated in the Proctor compaction test [32].

4.4 Inconsistency of compressive strength

Two samples broke with tensile cracks and had lower compressive strength (41.4 MPa and 40.1 MPa, respectively) than those with excellent concrete core failure (44.6 MPa). Tensile cracks discovered during testing indicate that the concrete failed in tension, as shown in Figure 7, before reaching its full compressive strength. Tensile cracks can also arise as a result of incorrect casting, handling, or testing of concrete samples. For example, voids or weak places in the specimen can occur if the concrete mixture is not properly mixed or compacted. Tensile cracks can form if these weak regions fail in tension during the compression test. Tensile cracks in a concrete cube or cylinder show that the concrete has not reached its maximum compressive strength and is therefore weaker than anticipated [23 & 24].

Figure 7: (a) satisfactory failure with crack parallel to the force applied; (b) unsatisfactory failure with tensile crack.

4.5 Fault of cube making

The manner of making the concrete cubes will affect their compressive strength; hence, the processes should be based on the standard BS EN 12390-2 [18]. Certain cubes are not casting correctly, and as can be observed, there is a large void left on the surface of the concrete as shown in Figure 8 (a), indicating that the rubber hammer does not impact the concrete in the mould after compacting to force out the large air void. Furthermore, wood fibre is observed on the surface of the cubes, as shown in Figure 8 (b), occupying a minor volume of the cubes, indicating that the mould does not clean effectively before casting the cubes, resulting in a lower-than-intended compressive strength. Additionally, the surface of the cube specimens is rough, and small, entrained air bubbles may be seen on the surface. It can be improved by thoroughly cleaning the inside surfaces of the moulds and applying sufficient oil to them.

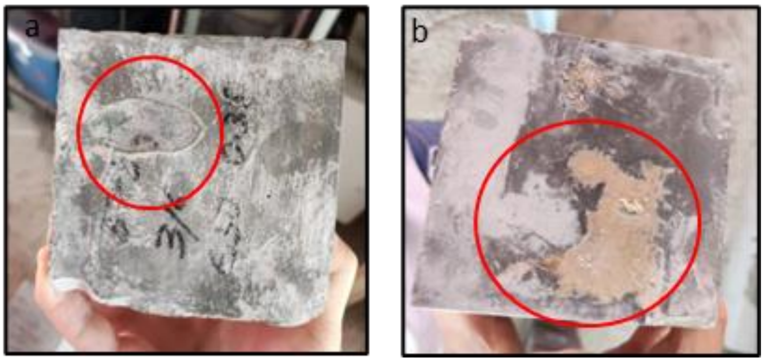

Figure 8: (a) Cube with the large void; (b) Cube with wood fiber.

5. CONCLUSION

In conclusion, construction material testing according to the standard is essential as quality assurance for the applications. There are a variety of tests to assess the characteristics or performance of the materials, but the quality of the test procedure should be as standards so that the results are accurate, consistent and reliable. Generally, issues related to workmanship and coordination will arise during testing or construction activities. As a remedy, it's critical to adhere to the proper building codes, regulations, and testing methods based on standards, to carry out comprehensive inspections, and to maintain quality control throughout the construction process.

ACKNOWLEDGEMENT

I would like to thank Soil Instruments (M) Sdn Bhd for taking me for practical purposes that allowed me to explore more about the lab and in-situ testing in the industry.

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