QUALITY SPECIFICATIONS OF CONCRETE MASONRY UNITS: A CASE STUDY OF THE INDUSTRIAL-ZONE IN AL-BAYDA CITY

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الملخص

يتم إنتاج وحدات الطوب الإسمنتي (CMUs) بشكل كبير في العديد من المصانع داخل مدينة البيضاء في ليبيا، ولكن لم يتم التحقيق بعد في مواصفات وحدات الطوب الإسمنتيCMU المنتجة داخل المدينة بعد. عدد كبير من مصانع وحدات الطوب الخرساني تنتشر داخل المنطقة الصناعية في مدينة البيضاء. تم استهداف جميع المصانع الأربعة عشر الموجودة داخل المنطقة الصناعية لتحديد مواصفات CMU الخاصة بكل منها. تم استخدام معيار الجمعية الأمريكية للاختبار والمواد (ASTM) المعروف دولياً لتحديد مواصفات وحدات الطوب الإسمنتي بالمنطقة المستهدفة. البيانات التي تم جمعها حددت مواصفات وحدات الطوب الإسمنتيCMU داخل المنطقة الصناعية بمدينة البيضاء مقارنة بالمعيار ASTM. وتركز الدراسة على الأبعاد والاختلافات المسموح بها ومتطلبات المقاومة للوحدات. أظهرت النتائج أن هناك مصنعين من أصل أربعة عشر مصنعاً كانا مطابقين لمواصفات ASTM C129 الخاصة بالحدود المسموح بها في الأبعاد وهما المصنعان I و N. جميع المصانع المستهدفة تنتج وحدات مصنفة على أنها ذات وزن عادي باستثناء المصنع B الذي أنتج وحدات ذات وزن متوسط. أظهرت بيانات مقاومة الضغط لصافي المساحة أن جميع المصانع تنتج وحدات طوب اسمنتي من النوع الغير قابل للتحميل. أحد عشر مصنعاً من أصل أربعة عشر فشلت في تلبية الحد الأدنى من المواصفات القياسية لقوة الضغط البالغة 4.14 ميجا باسكال. اجتازت ثلاثة مصانع فقط اختبار مقاومة الضغط، وهي I و M و D. نتج عن هذه الدراسة الميدانية استنتاج عام وهو أن جميع المصانع الأربعة عشر فشلت في تحقيق جميع المواصفات المطلوبة معاً من قبل المعيار ASTM.

ABSTRACT

Concrete masonry units (CMUs) have been excessively produced in many factories inside Al-Bayda city in Libya, however the specifications of the produced CMUs are not yet investigated. A large number of concrete masonry unit factories are spreading out across the Industrial Zone of Al-Bayda city. All of the 14 factories located in the Industrial Zone were targeted to determine their CMU specifications. The American Society for Testing and Materials (ASTM) standard was used to determine how Al-Bayda CMU specifications measure up to the ASTM standard. The study focuses on the dimensions and permissible variations, density classification requirements, and strength requirements of units. The results showed that two factories out of the fourteen conformed to the ASTM C129 permissible variations of dimensions namely, factory I and N. All targeted factories produced units classified as normal weight except for factory B which produced units with medium weight. The net area compressive strength data showed that all of the 14 factories produce a nonloadbearing CMU type. Eleven factories out of fourteen failed to meet the minimum compressive strength standard specification of 4.14 MPa. Only three factories passed the compressive strength test, namely I, M and D. The overall conclusion in this study case was that all 14 factories have failed to meet one or more of the specifications required by the ASTM standards.

KEYWORDS: ASTM Standards; Concrete Masonry Unit, Nonloadbearing; Dimensions; Oven-Dry Density; Absorption Test; Net Area Compressive Strength.

INTRODUCTION

Concrete masonry unit (CMU) is an essential basic unit that has been used in building constructions for decades [1]. In general, concrete blocks or units are divided into two main categories: solid concrete blocks and hollow concrete blocks. The solid concrete blocks are heavy-weight units that are used mostly for large-scale projects because they offer better stability. Hollow concrete blocks are units made of concrete that have hollow spaces between their walls. They have advantages of reducing labor cost, reducing construction time, saving cement and materials, and improving wall qualities such as noise and thermal insulation. The hollow concrete blocks come in different types such as: stretcher, double corner, low web bold beam block, control joint and concrete end block. The construction industry has long relied on concrete masonry units (CMUs) for both loadbearing and nonloadbearing applications. These units are versatile and durable, making them suitable for a wide range of building projects. Nonloadbearing CMUs also known as partition walls are primarily used to divide spaces within a building without providing structural support. They are commonly used in residential and commercial construction for interior walls and partitions [2].

Al-Bayda city is one of the largest cities in the east of Libya, located on the top of Al-Jabal Al-Akhdar (The Green Mountain about 600 meters above the sea level). Unlike most of Libyan cities, Al-Bayda has a quite cold rainy winter and sometimes experiences snow. Most buildings suffer from significant drop in temperature especially during winter due to poor construction and materials [3]. The strength parameters and resistance to environmental factors of a building depend on the quality of the CMU, however, information about the local CMUs specifications is simply not available.

World-wide there are many standards for specifying CMU. ASTM International is the most widely-used standard which contains minimum requirements that assure properties necessary for quality performance. These standards reflect the expert opinion of researchers, concrete masonry manufacturers, designers, contractors and others with an interest in quality standards for concrete masonry. Specifically, these standards include sampling, measurement of dimensions, absorption, and compressive strength [4].

The American Society for Testing and Materials, known as ASTM International, is an organization that publishes production and testing standards for various industries. These standards cover multiple materials, systems and products to encourage consistency and safety among manufacturers. These ASTM standards are crucial in evaluating the material, chemical, mechanical, and metallurgical properties. This information helps guide product manufacturers toward proper processing and application procedures. The references are based on ASTM C140 [5], ASTM C90 [6], ASTM C129 [7], and ASTM C1552 [8].

ASTM has established a standard for the sampling and testing of CMUs, known as ASTM C140. This standard outlines the requirements for the physical properties, dimensions, and performance of these units. It serves as a benchmark for the quality and consistency of CMUs produced within the United States. More specifically the ASTM C140 covers the required information about apparatus, materials, and procedures for capping concrete masonry units, including the compression testing. The test procedure requires six units of identical size and configuration to be selected for testing — three for compression test and three for absorption [5].

Another important test related to CMU is the Standard Specification for Loadbearing Concrete Masonry Units (ASTM C90) which covers both hollow and solid loadbearing concrete blocks. The minimum net area compressive strength required for

ASTM C90 loadbearing units is 13.8 MPa as an average of three units and in case of an individual unit, it is 12.4 MPa. Compressive strength is largely a function of the characteristics of the aggregate used in the units and may vary regionally according to the types of aggregates available. The ASTM C90 test contains minimum requirements that assure properties necessary for quality performance, including specified constituent materials, minimum face shell and web thicknesses, minimum compressive strength, permissible variations in dimensions, and finish and appearance criteria [6]. ASTM C129 covers hollow nonloadbearing units as well as solid nonloadbearing units. These units are used in nonloadbearing partitions and not appropriate for exterior walls. At the job site these units should be clearly labeled as nonloadbearing units. The minimum net area compressive strength requirements are 4.14 MPa as an average of three units and in case of an individual unit; it is 3.45 MPa [7].

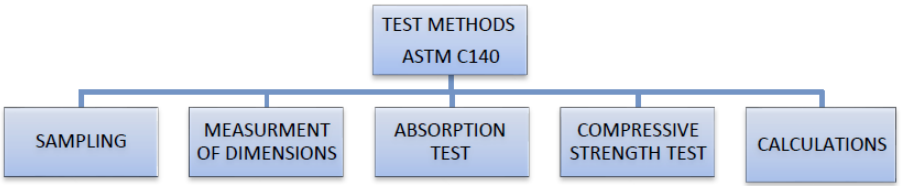
In order for the load to be distributed during test in an evenly uniform manner, capping of a leveling layer is applied on both sides of the unit. This practice describes procedures for providing plane surfaces "capping" on the two bearing surfaces of units and prisms. The purpose of this standard [8] is to provide consistent and standardized procedures for capping units and prisms for compression testing. The procedures are based on those contained in Test Methods ASTM C140 [5], Practice ASTM C1552 [8].

This project aims to determine the specifications of CMUs produced in the Industrial-Zone of Al-Bayda city using the ASTM standards. The study will focus on the dimensions and permissible variations, density classification, absorption, and compressive strength of the units. The data collected will be analyzed to determine how Al-Bayda CMUs measure up to the ASTM standards. The Industrial-Zone is located in the southern part of Al-Bayda city, highlighted in yellow color in Figure (1). In this study, only the area inside the red box in Figure (1) are considered since the majority of the CMU factories are located in this area.

Figure 1: Industrial-Zone in the southern part of Al-Bayda, Libya.

TESTING METHODS

The ASTM C140 covers the standard methods for sampling and testing of CMUs and related units for dimensions, absorption, and compressive strength tests. These are the characteristics that should be determined for any CMU according to the ASTM C140. The test procedure requires 6 units of identical size and configuration to be selected for testing. After all 6 units sampled and measured, 3 units will be used toward absorption test and the other 3 units will be used for the compression test.



In this study, we targeted all the factories inside the Industrial-Zone of Al-Bayda city. Figure (2) shows the locations of the factories inside the targeted area. The total number of factories in this area was 17 factories. After scanning the area only 14 factories were in operation and though were targeted in this study. To preserve confidentiality of their information, the targeted 14 factories were named a random order from A to N.

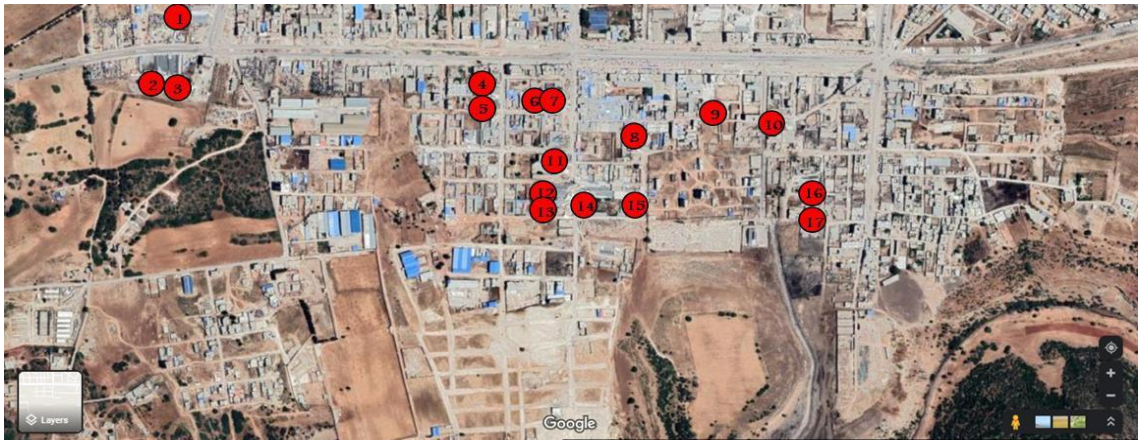


Figure 2: Number of CMU factories inside the targeted Industrial-Zone.

SAMPLING

Test specimens must be chosen in way that they represent the entire units at the job site. The selection of the samples should be random and factory workers should not pre-informed about the sampling purpose. All specimens should have the same configuration and dimensions. According to the ASTM C140 sampling procedure 6 units should be selected from each lot of 10,000 units and 12 units from each lot of 10,000 to 100,000 units. Lots of more than 100,000 units, 6 units should be selected from each 50,000 units. Since, the average production of CMUs per factory inside the Industrial-Zone is in the range of 10,000 units per day therefore, 6 units per each factory should be selected as specified in ASTM C140.

MEASUREMENT OF DIMENSIONS

CMUs having size of 400mm in length, 200mm in width, and 200mm in height are targeted in this case study. Upon arriving to the lab, test specimens are coded and numbered. ASTM C140 specifications required that the length (L), the width (W), the height (H), the face shell thickness (Tfs), and the web thickness (Tw) of each unit are recorded, see Figure (3).

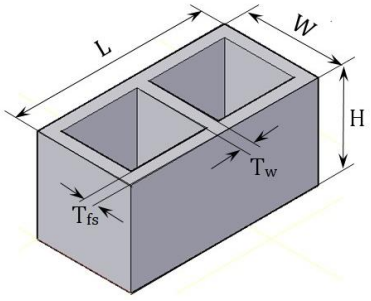


Figure 3: Dimensions measured as specified in ASTM-C140.

The average value of each dimension for each factory is listed in Table (1). These values will be used to measure specifications requested by the ASTM later on.

Table 1: Average dimension calculated from 3 units for each factory.

Factory Code	*W (cm)*	*H (cm)*	*L (cm)*	*Tfs (cm)*	*Tw (cm)*
A	20.08	19.57	39.68	2.82	2.75
B	19.80	19.62	40.00	2.37	2.28
C	19.87	19.24	40.10	2.71	2.88
D	19.83	19.50	39.43	2.64	2.58
E	19.57	19.57	39.70	2.40	2.30
F	19.88	19.07	40.23	2.52	2.65
G	19.93	19.67	39.78	2.45	2.50
H	19.87	19.33	40.03	2.52	2.73
I	19.85	19.88	40.28	2.50	2.60
J	19.78	18.78	39.58	2.57	2.57
K	19.68	19.07	39.85	2.50	2.64
L	19.82	19.22	39.95	2.50	2.48
M	19.88	21.07	39.92	2.45	2.70
N	19.92	19.98	40.03	2.43	2.65

ABSORPTION TEST

There are several reasons behind variation in absorption such as mixing quality, and/or compaction of the concrete mix. It is equally important that variation in absorption could mean variations in compressive strength, tensile strength, and durability. Three units should be collected from each factory to be used as test specimens for the absorption test. The procedures of this test are specified in the ASTM C140 standard. According to this standard the specimens should be weighed upon arriving and recorded as received weight (*Wr*). Then test specimens should be immersed in water for 24 hours at a temperature ranges between 15.6^{o}C and 26.7^{o}C, Figure (4).

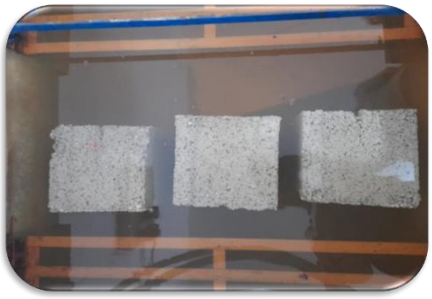


Figure 4: Test specimens immersed in water for 24 hours.

After 24 hours' specimens should be weighed while submerged in water and the weight is recorded as immersed weight (*Wi*). Then the specimens are removed from water and allowed to drain for 1 min on a coarse wire mesh (9.5mm), Figure (5). Then specimens cleaned with damp cloth to remove any visible surface water and the weight recorded in this case as saturated weight (*Ws*).

Figure 5: Specimens are removed from water and allowed to drain for 1 min.

The last step is to dry all 3 specimens in a ventilated oven at a temperature 100^{o}C to 115^{o}C for 24 hours as shown in Figure (6). Specimens should be weighed and returned to the ventilation oven for 2 hours and then weighed again. This drying process for 2 hours interval each will be repeated until the loss in weight between to intervals is not more than 0.2%. This should be recorded as the oven-dry weight of the specimen (*Wd*).

Figure 6: Specimens dried in an oven at a temperature of 100^{o}C to 115^{o}C for 24 hours.

The average value of saturated weight (*Ws*), immersed weight (*Wi*), and oven-dry weight (*Wd*) for each factory evaluated as the average of 3 units are listed in Table (2). These values will be used to calculate specifications requested by the ASTM later on.

Table 2: Average saturated weight, immersed weight, and oven-dry weight evaluated as the average of 3 units for each factory

Factory Code	*Wr* (kg)	*Ws* (kg)	*Wi* (kg)	*Wd* (kg)
A	15.37	16.30	9.17	15.01
B	16.18	17.47	8.60	15.82
C	16.07	16.61	9.23	15.44
D	15.90	16.53	9.23	15.39
E	15.81	16.98	9.40	15.91
F	14.45	15.78	8.85	14.43
G	15.26	15.83	8.83	14.58
H	14.55	15.70	8.93	14.44
I	17.79	18.37	9.98	17.05
J	15.68	16.71	9.15	15.49
K	15.45	16.38	9.27	15.17
L	16.74	17.67	9.63	16.32
M	17.44	18.90	10.33	17.45
N	15.44	16.58	9.17	15.29

During the absorption test, units are immersed in water and then oven-dried. Therefore, it is important to note that these units should not be used for the compression testing because the moisture content will affect the results.

COMPRESSIVE STRENGTH TEST

There are two standards for the specifications of CMU according to the ASTM C140, one is for the specification of Nonloadbearing Concrete Masonry Units (ASTM C129) and the other is the specification of Loadbearing Concrete Masonry Units (ASTM C90). This classification depends on the minimum net area compressive strength as shown in Table (3).

Table 3: Minimum net area compressive Strength required for both loadbearing and nonloadbearing CMUs.

Type	Minimum compressive strength based on net area (MPa)	
	Average of 3 units	Individual unit
Loadbearing	13.8	12.4
Nonloadbearing	4.14	3.45

Three full size units are highly recommended to be used in the compressive strength test. The main goal of the compressive strength test is to ensure that concrete masonry unit meets the minimum strength required by either the loadbearing ASTM C90 standard or the nonloadbearing ASTM C129 standard. Compressive strength test is the most popular test because it is easier and less expensive to perform than similar tests on masonry units. It is important to note that this test requires high accurate testing process. The compressive strength test according to ASTM C140 requires an appropriate test machine, capping, and speed test.

Capping

According to ASTM C140 standard both sides of the test specimen must be capped by using sulfur or high-strength gypsum that conforms to the ASTM C1552 standard, Figure (7). Capping surfaces ensure proper alignment between the specimen surface and the test machine. The capping layer ensures even distribution of forces over the entire surfaces of the specimens. This will eliminate point loads due to uneven surface. Therefore the test results become more uniform and reliable.

Figure 7: Test specimen capped according to the ASTM-C1552 standard.

According to the ASTM C1552 standard [8], the capping surface needs to be plane and rigid. In order for the force to be evenly distributed, the capping surface must not be deflected. It is recommended that the capping station consist of a 13 mm thick glass plate to provide a smooth replaceable wear surface. The glass plate placed on top of 25mm thick steel plate to provide the required stiffness.

Loading rate of the test

The rate of speed can significantly affect the compression test results. Using a rapid speed of loading will result higher apparent failure. Therefore, the ASTM C140 standard requires application of one half of the expected maximum load at any convenient rate and then increasing rate of speed so that failure should happen not less than 1min nor more than 2min.

To ensure test procedure comply with the ASTM C140 standard number of pretrial tests have been conducted until the right setup of the test machine has been found. At the beginning of test a rate of 3 m/min is used with until the reading of load recorded 50kN. Then the speed testing rate increased to 5m/min which ensure failure of the specimen within the 1 to 2min time window. The setup of the compression test is shown in Figure (8).

Figure 8: Compression test setup.

After the test specimen failed, the maximum compressive load is recorded as (*Pmax*). Figure (9) shows the maximum load measured for each factory as an average of 3 units. Figure (9) shows that factory I recorded the maximum value among all 14 factories with a value of 206.47 kN. Factory F recorded the minimum value among all 14 factories with a value of 103.17 kN.

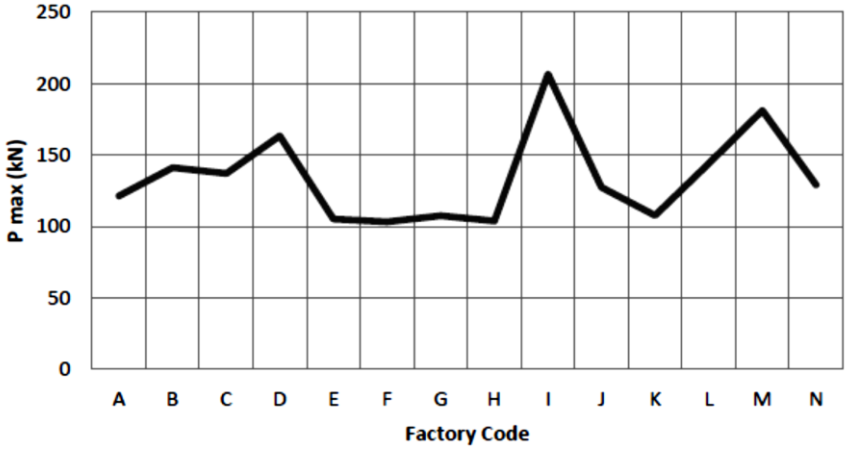


Figure 9: Maximum load (Pmax) measured experimentally as the average of 3 units for all 14 factories.

CALCULATIONS AND RESULTS

The aim of this section is to use the collected data during the measurement of dimensions, absorption tests, and compressive strength tests to calculate the following characteristics: dimensions and permissible variations, density classification, and net area compressive strength. These characteristics will be calculated for each factory to evaluate the quality of CMU produced inside the targeted Industrial-Zone of Al-Bayda city according to the ASTM C140 and ASTM C129 standards.

Dimensions and Permissible Variations

There are permissible variations in these standard dimensions of the CMU. Factory shall produce CMU with permissible variations in dimensions that conform to the ASTM standard specification. These dimensions are critical for the end use of the unit. According to ASTM C129, face shell thickness (Tfs) of any CMU should not be less than 13mm. Values of the face shell thickness calculated from the average of 3units for each factory are shown in Figure (10).

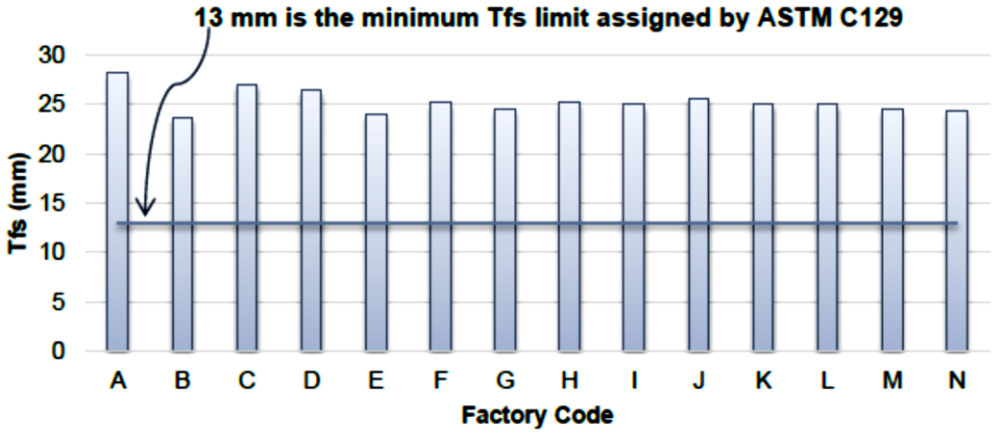


Figure 10: Values of the face shell thickness of average of CMU for all factories.

According to ASTM C-140, the web thickness (Tw) should not be less than 19mm. Values calculated from the average of 3 units of the web thickness for each factory are shown in Figure (11).

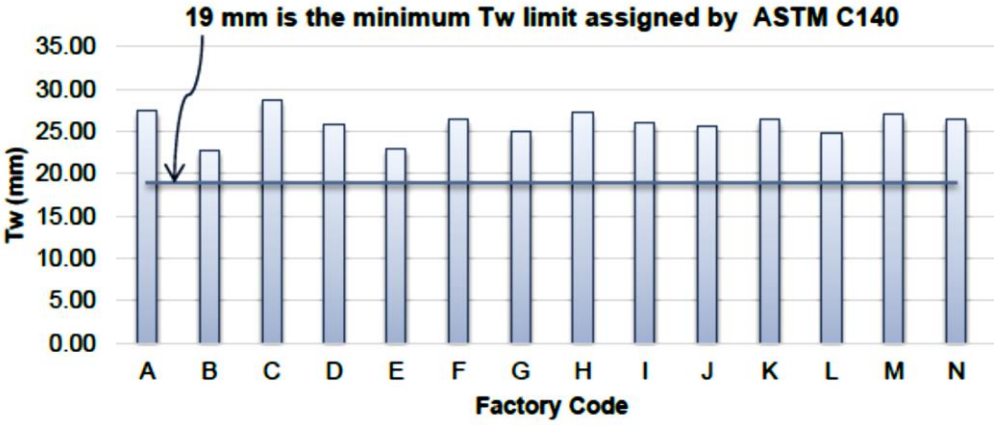


Figure 11: Values of the unit web thickness of average of CMU for all factories.

Figure (10) and Figure (11) show that CMUs produced in all fourteen factories are above the minimum value of the face shell thickness of 13mm and above the minimum value of web thickness of 19mm that requested by the ASTM C129 and ASTM C140 standard specifications respectively.

As for the overall dimensions of the CMU namely, the unit width (W), the unit height (H), and the unit length (L), they should not differ by more than ±3.2 mm from the specified standard dimensions (200mm x 200mm x 400mm) according the ASTM C129 standard. Figure (12) shows the variation in unit width, unit height, and unit length with respect to the standard values of ±3.2 mm. These average values calculated from the average of 3units of each factory.

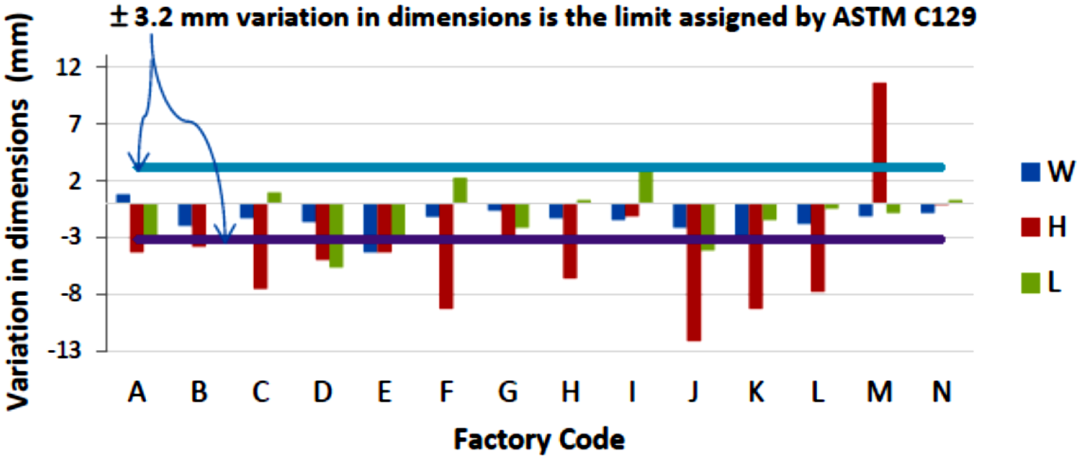


Figure 12: Average variations of unit dimension for all 14 factories with permissible variation limits.

Figure (12) shows that a total of eleven factories namely, A, B, C, D, E, F, G, H, J, K, and L, produce units with height (H) variation less than -3.2 mm. This variation in unit height is less than the permissible value requested by the ASTM C129 standard. On the other hand, factory M produces units with height (H) variation more than the permissible variation value of +3.2mm that requested by the same ASTM C129 standard.

As for the width (W), E and K factories failed to produce units that comply with the permissible values of ±3.2 mm according to the ASTM-C129 standard. As for the

length (L) A, D, and J factories failed to produce units that comply with the permissible values of ±3.2mm according to the ASTM C129 standard.

Density Classification

Data collected from absorption tests were used to calculate oven-dry density. It is an indication of the compaction level of the concrete unit and it is also an indication of the volume of gaps inside the unit. In ASTM C140 standard the so called ***Oven-Dry Density*** is calculated by using equation (1) and the resulting Density for Nonloadbearing CMU (ASTM C129) shall conform to one of three classifications prescribed in Table (4).

Table 4: Density classification requirements

Density Classification	Oven-Dray Density of Concrete (kg/m^3) Average of 3 Units
Light Weight	Less than 1680
Medium Weight	1680 to less than 2000
Normal Weight	2000 or more

Oven-Dry Density *(D)* for weight classification is determined from the following equation:

$$Oven-Dry\ Density\ (D),\ k\,g/m^3 = \frac{W_d}{W_s - W_i} \times 1000 \quad (1)$$

where: *Ws: saturated weight of specimen, (kg),*
Wi: immersed weight of specimen, (kg), and
Wd: oven-dry weight of specimen, (kg).

Figure (13) shows the calculated Oven-Dry Density values for all targeted fourteen factories. The values of Oven-Dry Density for all factories are above 2000 kg/m^3 except for factory B. This means the majority of factories produce CMUs with a normal weight classification except for factory B which returns a value that lie in between 1680 and 2000 kg/m^3 making it a medium weight classification units according to ASTM C129 standard.

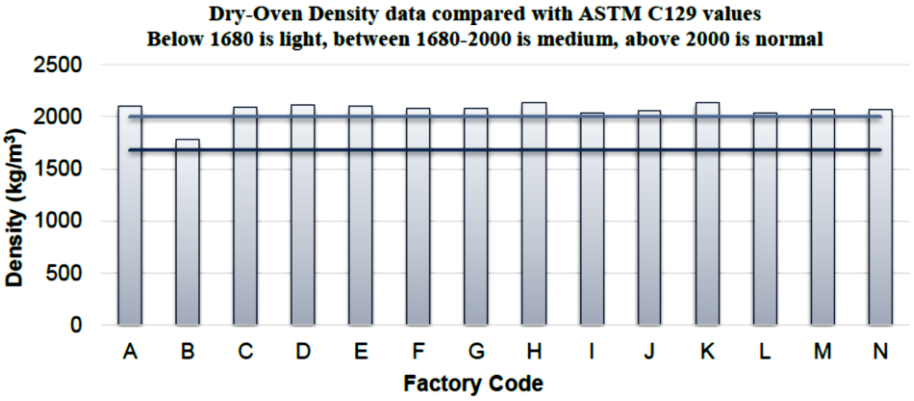


Figure 13: Average unit weight collected from all 14 factories.

Compressive Strength

According to the ASTM C140 specification the net area compressive strength of CMU has to be reported. First, the net volume of concrete in a unit is determined as water displacement using the following equation:

$$Net\ Volume\ (V_n), mm^3 = \frac{W_d}{D} = (W_s - W_i) \times 10^6 \quad (2)$$

Then the net area of the CMU, shown in Figure (14), is calculated. The net area represents the percentage of solid material in the cross section and it can be calculated from the following equation:

$$Average\ Net\ Area\ (A_n), mm^2 = \frac{V_n}{H} \quad (3)$$

where:
Vn: net volume of specimen, (mm^3), and
H: average height of specimen, (mm)

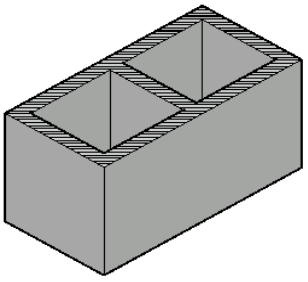


Figure 14: The shaded area in the figure shows the net area of CMU.

Finally, the net area compressive strength can be calculated as:

$$Net\ Area\ Compressive\ Strength,\ (MPa) = \frac{P_{max}}{A_n} \quad (4)$$

where:
Pmax: maximum compressive load, (N), and
An: average net area of specimen, (mm^2).

Figure (15) represents the values of the net area compressive strength calculated for the all fourteen factories. Nonloadbearing CMU is required to comply with a minimum net area compressive strength of 4.14 MPa according to the ASTM C129 standard. This value calculated from the average of 3 units.

Units collected from factory D recorded an amount of 4.36 MPa compressive strength, Units collected from factory I recorded an amount of 4.94 MPa, and Units collected from factory M recorded an amount of 4.47 MPa. Units collected from the rest of factories show a compressive strength ranged between 2.71MPa and 3.49 MPa which are below the minimum limit of 4.14 MPa compressive strength specified in the ASTM C129 standard as shown in Figure (15).

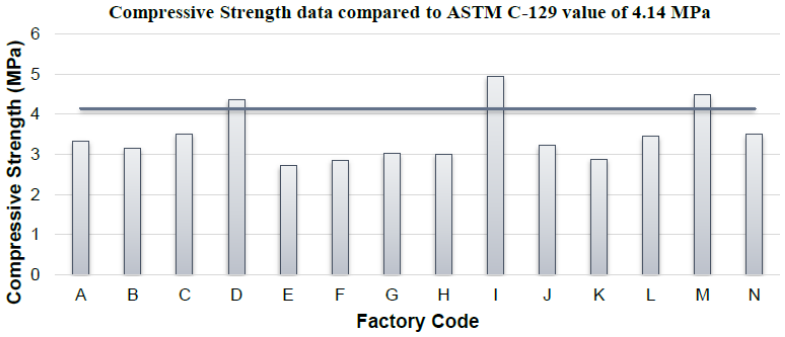


Figure 15: Average net area compressive strength calculated for all 14 factories.

CONCLUSIONS

The specifications of the concrete masonry units (CMUs) produced in Al-Bayda city in Libya were under investigation. The study targeted fourteen CMU factories in the Industrial-Zone in the city. The International American Society for Testing and Material

Standard (ASTM) was used. All factories inside the Industrial-Zone were found to produce a nonloadbearing CMU type. Therefore, the collected data from the 14 factories was used to evaluate dimensions' permissible variations, density classification, and compressive strength of CMUs according to ASTM C129.

While all factories have passed the standard requirements of the minimum 13mm face shell thickness and the minimum 19mm web thickness, it has been found that 12 out of the 14 factories have failed to meet at least one of the other standard requirements of the dimension permissible variations. In summary, only two factories (I and N) conform to the ASTM C129 and ASTM C140 permissible variations of dimensions. Regarding the density classification, all factories produced units that were classified as normal weight except for factory B which produced units with a medium weight. The net area compressive strength test results show that 11 factories failed to meet the minimum compressive strength of 4.14 MPa for an average of 3 units (ASTM C129). The factories that passed the compressive strength test were Factory I (maximum compressive strength of 4.94 MPa), factory M (4.47 MPa), and factory D (4.36 MPa). As a conclusion, all targeted factories failed to meet one or more of the standard ASTM C129 specifications.

RECOMMENDATIONS AND FUTURE WORK

Tests conducted in this study show that the majority of the factories produce CMU not comply with the ASTM standard. Further investigations need to be done to know the reasons behind these findings. The most important recommendation of this work is to investigate the production procedures inside these factories specially the materials. Factories have to follow the ASTM specifications for cement, aggregates, and any other additives during production. There are several ASTM standards in materials that have to be followed to produce nonloadbearing CMU conform to the ASTM standard. For example, Portland cement of specification ASTM-C150/C150M has to be used for normal weight Aggregates type specification ASTM-C33/C33M should be followed and if lightweight aggregates is to be used it should have ASTM-C331/C331M specifications. These types of information will be of highly interest to factories to improve their CMU quality production and definitely will benefit end user costumers.

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