

Economical and Structural Feasibility of Concrete Cellular and Solid Blocks in Kurdistan Region

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Abstract—Cellular concrete blocks are the major building materials in Kurdistan Region in Iraq. This study is carried out to check the economical and structural feasibility. The integrity of the blocks as well as its industrial production process compared with local and international standards. Recommendations for the concrete block production have been given in this paper. Samples from 10 local factories of total 60 blocks have been collected and tested at Koya University Laboratory. The carried out tests covered the dimensions, compression strength and water absorption of the samples. The results of this research study were compared with the requirements of the Iraqi and European specifications. They showed that the products of all factories do not fulfil the specified requirements. The dimensions of specimens exhibited relatively high deviations with no recommended tolerances for dimensions of the blocks. The results analysis showed that the weight of the 400x200x200mm block size was about 20-23 kg and the size of the represented voids was about 60% of the volume. This study made some regulatory recommendations to standardise the concrete block production in the region.

Index Terms—Building standard codes, cellular concrete block, eurocode, structural feasibility.

I. INTRODUCTION

“Concrete is one of the most basic building blocks of modern life that most people take for granted” (Neville, 1996). Historical records show that concrete mortar as a building product was used by the Romans as early as 200 B.C. to erect

stone walls in the construction of buildings. By fall of the Romans Empire in 5th century much of the learned concrete technology was lost. It was not until 1824 that the English stonemason Joseph Aspdin developed Portland cement, which became a major component of today's concrete products (GOI, 2012).

To In 1890 the first hollow concrete block was designed by Harmon S. Palmer in the United States. After 10 years of experimenting, Palmer patented the design in 1900. Palmer's blocks were produced in $203 \times 254 \times 762 \text{ mm}^3$. The blocks were so heavy they had to be lifted with a small crane (Hornbostel, 1991). “By 1905, an estimated 1,500 companies were manufacturing concrete blocks in the United States. These early blocks were usually cast by hand, and the average output was about 10 blocks per person per hour. Today, concrete block manufacturing is a highly automated process that can produce up to 2,000 blocks per hour” (Cavette, 2007).

The Kurdistan Region in Iraq has been going through a rapid building boom since 2004. Due to geopolitical situation of the region commercial building materials have largely been limited to concrete products in particular concrete blocks. The use of concrete blocks is found suitable in region where other building elements are costly, and not available (Barbosa, et al., 2010). These blocks are being widely used in construction of residential, factories and multi-storied buildings (see Fig. 1). Despite these facts, the composite strength of hollow and cellular block concrete block masonry still represents a real challenge in the region.

In general the concrete blocks as precast masonry units such as Hollow and Solid normal and lightweight concrete blocks of different sizes are used for erecting walls in various conditions. Depending upon the structural requirements of masonry unit, concrete mixtures are prepared using components available locally or most economical distance (Chandra and Bhise, 1994).

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Fig. 1. Concrete structure erected with diaphragm Cellular Concrete Block (Photo by Authors)

The most common concrete block type in Kurdistan Region is Cellular block In-line Void type. “Cellular blocks are masonry units that contain one or more formed voids that do not fully penetrate the block. The selection of cellular blocks can have significant advantages over solid blocks where weight is a prime consideration. The reduced unit weight makes for ease of handling, reduced floor/foundation loading, economic and efficient productivity. The Cellular blocks do not require special laying techniques and can be laid on a full bed of standard or general purpose mortar for most applications” (CBA, 2007).

In Kurdistan region the cellular blocks are used also as a replacement for solid blocks. According to the UK based Concrete Block Association (CBA) by selecting the correct specification, cellular blocks can be used in the following common applications (CBA, 2007): Infill in framed structures, providing improved insulation as the inner leaf to external cavity walls, Outer leaves of cavity walls when protected e.g. render, tiling etc., Single leaf external walls when protected e.g. render, tiling etc., Internal partitions, and sound separating walls when supported by acoustic test evidence

In the regional building market there are several face sizes (length \times width \times height) of $400 \times 200 \times 200 \text{ mm}^3$, $400 \times 200 \times 150 \text{ mm}^3$ and $300 \times 300 \times 300 \text{ mm}^3$ cellular aggregate concrete blocks are available. These are the most common sizes used in construction of domestic dwellings. CBA specifies that based on the UK industrial standards, cellular blocks are normally available in compressive strengths from 2.90 MPa to 22.50 MPa. Common strengths are 3.60 MPa and 7.30 MPa (CBA, 2008).

This study examined product of 10 different local factories which supply the region with concrete cellular blocks. The specimens were tested and analysed against available standards, where some practical recommendations have been provided accordingly.

II. MAKING OF CONCRETE BLOCK

Most people who work with blocks probably don't give much thought to how it is produced. Koski (1992) emphasised that people's main concerns are that the block's colour and dimensions are uniform, and that it meets other appropriate specifications (Koski, 1992). Basic knowledge across the

industry needed to understand that concrete mixture can be turned into precast masonry elements such as different type of concrete blocks of suitable sizes which are used for load and non-load bearing units for masonry walls. The concrete mix used for normal hollow and solid blocks shall not be richer than one part by volume of cement to 6 parts by volume of combined room dry aggregates before mixing (Kaushal, 2011). Normal weight blocks are made with cement, sand, gravel, crushed stone and air-cooled slag.

The old Iraqi specification standard (ISS) from 1987 gives directions on how to produce the concrete blocks. ISS was created based on American Society for Testing and Materials (ASTM) Specification of materials Part 16 of year 1986, the British Specification (BS) No. 1364 and No. 2028 of year 1968 and Japanese specification A No. 5406 of year 1976. The load-bearing concrete masonry units part of ISS covers resolutions for Dimensions, Categories and Physical requirements in details. The requirements provide instructions for class (A) block as general use in the internal or external walls which are exposed to moisture or climate changes under or above ground level with variation of any dimension must be no more than $\pm 3 \text{ mm}$. The physical requirements of cellular concrete blocks with an extraction of average value provided for solid and hollow blocks recommended as a minimum compressive strength of 10 N/mm^2 and maximum water absorption of 12.5%, (Siram, 2012). It is also advised that concrete blocks must not be used before 14 days of their production. Factories which failed complying with these ISS recommendations were fined and their product were removed from the market (ISS, 1987). However, since the release of ISS in 1987 Iraq has gone through two wars and ongoing sectarian war therefore follows up regulation has not been a priority for the market in this country.

The study of this paper required collection of specimens from local concrete production factories. None of the visited factories applied any standard regulations for their production but rules of thumbs. In general at the visited factories they put cement in vertical silos, the sand and gravel are placed nearby as fill (No-stock). Then, they put gravel, sand, cement and water in conic mobile mixing to mix. The quantity of material is measured by using spade and naked eyes. The water for the mixture is added based on pure thumb rules without any measurements. The quantity of water is depending on the temperature at the mixing time. Finally, the mobile mixing is driven to the location of casting.

The casting of the cellular blocks includes following stages, a) placing the molds on a clean plane ground, b) putting the concrete mixture in the molds, and c) compacting the mixture the steel sticks unit, which is available in the mobile mixing machine. The number of compaction blows is determined manually. Immediately the molds are removed and the process is repeated. The curing is started when all castings are completed. The curing process is done directly by using water sprinkle machine. The curing is continued for three days and then, concrete blocks are stored for immediate delivery to the building sites.

III. SPECIMENS

To conduct this research study 60 specimens from 10 different local factories were collected and transferred to laboratory for testing, see Fig 2. All specimens were measured for length, width and height, as well as minimum thickness of face, shells and webs. These blocks were tested for water absorption, block density and compressive strength.



Fig. 2. Factory site where specimens have been taken (Photo: Authors)

The specimens were tested within 72 hours after delivery to the laboratory, where they were kept under laboratory temperature and humidity. For the purpose of this study the specimens were all aged for 28 days and cured normally. All factories have given their consent to anonymously use their specimens for the purpose of this study. All data related to the specimens are available by request for future studies.

A. The Blocks' Density

The dimensions of each block were measured in millimetre and the overall volume calculated in cubic meters. The blocks were then weighted in kilograms to the nearest 10 gm. The density of each block is calculated as follows:

$$\text{Density} = \text{Mass of block} / \text{Solid Vol of block} \quad (1)$$

where; the density is measured in $[\text{kg}/\text{m}^3]$, mass in $[\text{kg}]$, solid volume in $[\text{m}^3]$.

The blocks of all factories have dry density more than recommended $2000 \text{ kg}/\text{m}^3$ (ISS, 1987), where the maximum dry density was $2483 \text{ kg}/\text{m}^3$, see Fig 3 for more details.

The recommendation by standard specifications suggests an allowed tolerance on the declared density value of $\pm 10\%$ but closer tolerances may be declared on both gross and net density (CBA, 2008). The gross density of aggregate concrete masonry units ranges from about $1700 \text{ kg}/\text{m}^3$ to $2400 \text{ kg}/\text{m}^3$. According to modern building standard codes such as Eurocode EN 772-13 manufacturers are required to provide data relevant to the density of their products, which allow for

calculation of dead load forces, sound insulation or thermal performance and the surface mass of a given section of masonry can be determined (DeVekey, 2001).

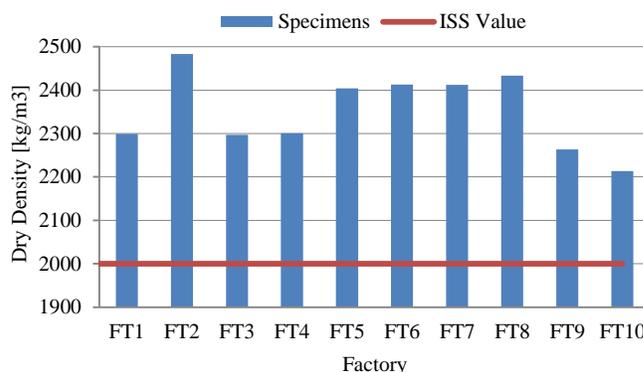


Fig. 3. Dry density of the blocks for different factories

The solid to void ratio of tested specimens indicated 10% to 12% below 75% recommended ratio by ISS as illustrated in Fig 4. This means that the amount of mixture used to produce these blocks are lower than recommended ISS guidelines.

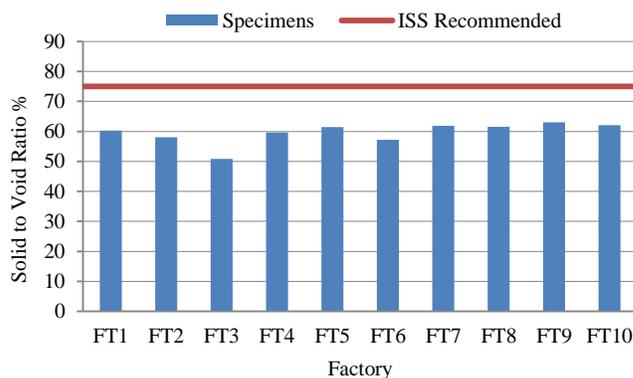


Fig. 4. Solid to void ratio of the blocks for different factories.

B. The Blocks' Water Absorption

It is recommended by CBA to consider water absorption only in the case of CBA units with no applied finishing (CBA, 2008). Most of the units tested in this study are used with applied finishing but this does not take place immediately. However, based on recommendations from CBA, the specimens were tested for water absorption level. The water absorption calculates as $\text{Water Absorption \%} = (A - B) / B * 100$, where (A) is wet mass of unit in kg and (B) dry mass of unit in kg (Kaushal, 2011). The collected specimens from factories were proven to have water absorption level less than 12.5%, a maximum recommended level for water absorption by ISS which is indicated in Fig 5. The Sieve Analysis of specimens revealed that the use of good grading quality of sand and gravel which is available locally to these factories causing lower water absorption level. Also, it is

widely believed that curing conditions can greatly affect the water absorption of concrete. Based on the curing conditions Zang (2014) stated that the concrete which was exposed to air curing exhibited low water absorption. (Zhang and Zong, 2014).

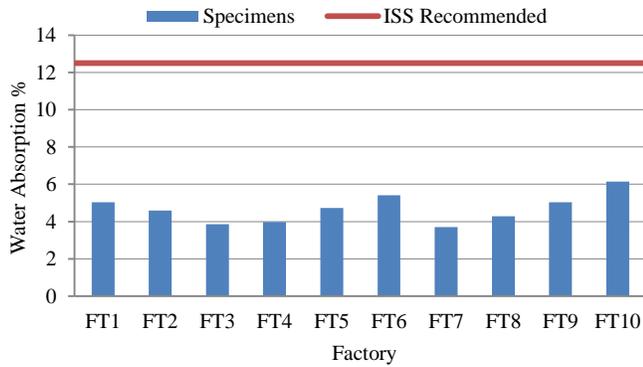


Fig. 5. Water absorption of the blocks for different factories.

C. Testing Procedure

The comprehensive testing process was carried out in the Laboratory of Civil and Structural Engineering at Koya University. Specimens were tested with the centroid of their bearing surfaces aligned vertically with the centre of thrust of the spherically seated steel bearing blocks of the testing machine, see Fig 6. The load up to one-half of the expected maximum load was applied at any convenient rate, after which the control of the machine was adjusted as required to give a uniform rate of travel of the moving head such that the remaining load was applied about two minutes.



Fig. 6. The Compression Testing Machine (CTM) (Photo: Authors)

The compressive strength of the concrete blocks units were measured by Compression Testing Machine (CTM) as the maximum load in Newton divided by the gross cross sectional area of the unit in square millimetres which is the total area occupied by a block on its bedding face, including areas of the cavities and end recesses. It is round up to the nearest 0.1 N/mm² for each tested specimen and then an average value is

calculated for 6 blocks from the same factory.

The following graph shows the average value of compressive strength of 6 blocks from each examined factory. The distributed value shows that most of the strength are over the minimum acceptable on average 10 MPa based on Iraqi specifications (CBA, 2008). The specification gives standard values for solid and hollow concrete blocks. For this study we have taken an average advised values for class A of Solid and Hollow Concrete blocks as a reference value for compressive strength of Cellular Concrete Blocks. Just 4 out of 10 factories satisfied ISS requirements, which mean more than half of factories failed to satisfy ISS as indicated Fig 7.

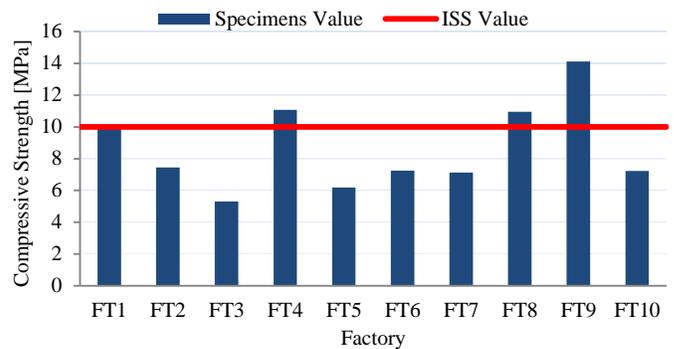


Fig. 7. Compressive strength of the blocks for different factories.

The average compressive strength of only four factories (FT1, FT4, FT8 and FT9) are satisfactory as compared with ISS guidelines. Fig. 8 shows that the lower limit of the average compressive strength is much lower than the minimum value recommended by ISS of 10 MPa (ISS, 1987). The combo graph of Fig. 8 clearly shows that the mixture proportion of the concrete block is irregular in various factories. They use more sand and gravel with higher density than cement, which leads to lower compressive strength and higher density with less solid material (Sturgeon, 2013). By mixing the right quantities of various sizes of gravel and sand and appropriate degree of compaction it is possible to achieve a dense and strong concrete (Johannessen, 2008).

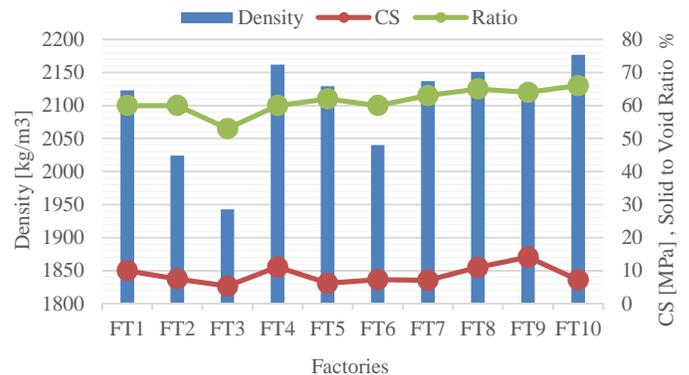


Fig. 8. Relational comparison among compressive strength, solid ratio and density of specimens.

Fig. 9 and Fig. 10 show the length, width and height of blocks for different factories. The actual measurement of tested specimens indicates huge variations in sizes compared with recommended values by ISS. Nevertheless, the latest recommendation by Eurocode BS EN 771-3 gives tolerance of +3, -5mm on all dimensions for all classes of concrete blocks (CBA, 2008).

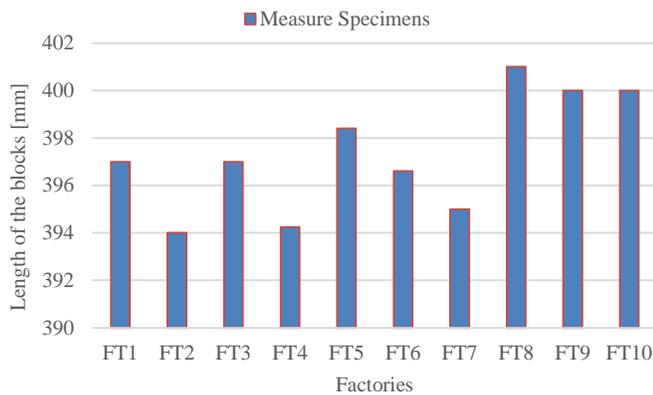


Fig. 9. Length of the blocks for different factories.

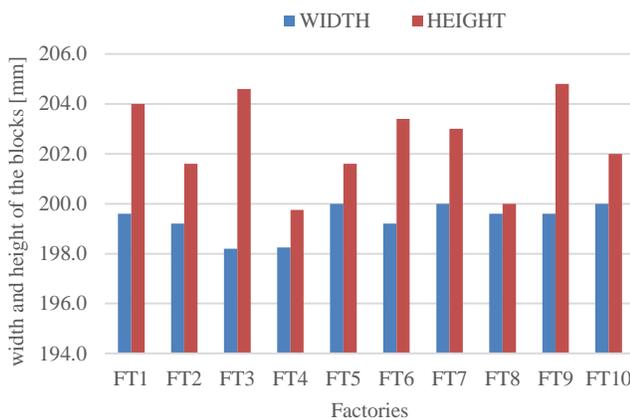


Fig. 10. Width and Height of the blocks for different factories.

IV. ECONOMIC FEASIBILITY

Stability, resistance, serviceability, durability and economic feasibility of structure are the primary requirements for market evaluation of any building project. In fact, the best viable construction is the one which shows an optimise balance among these primary factors. The comparative research studies have been the focus of finding an optimum way of selecting various concrete blocks or bricks for erecting the building. Ahmad and et al., (2014) in their research study claimed that the compressive strength of hollow concrete block masonry wall was lower than brick masonry wall but block masonry is economical than brick masonry (Ahmad et al., 2014).

The building materials' market in Kurdistan region has been

limited to few units such as concrete blocks, Bricks, and stones. The cost of using these building materials is measured by production and transportation costs as well as time used to erecting the building. A market survey of price, availability of craftsmen and locality of these materials show that cellular blocks are most popular amongst consumers, see Table I.

TABLE I
ESTIMATE MARKET VALUE OF COMPARABLE BUILDING MATERIALS

Material	Cellular Block	Brick	Natural Stone
Weight {kg/m ³ }	2110	1890	2900
Price {per m ² }	\$48	\$96	\$143
Craftsmen {Cost/m ² }	\$20	\$28	\$55
Craftsmen availability	Common	Moderate	Rare

The building construction market is booming by first time homeowners and private investors (Duhoki, 2015, pers. comm., 3 Sep). Both categories are trying to build with least costs. In the lack of effective building regulators the market is dominated with irregular building practices which make cellular concrete block as a fast and least costly erecting building material an attractive product in the market of Kurdistan Region. The traditional craftsmanship for erecting natural stone wall is very rare and normally hired from East Kurdistan says Faruk a local traditional builder from Tewelle Town (Dawood, 2015, pers. comm., 8 Oct).

V. RESULT ANALYSIS

This research study shows that most of the blocks produced by the local factories are non-bearing blocks and are used to build internal and external walls of buildings.

There are clear issues with standard dimensions of all tested blocks especially in the height of the blocks. This will create issues during application process, such as erecting walls. Normally the blocks are casted on uneven unprepared industrial ground in open space which results in uneven bases for the blocks; therefore there will be need for more mortar during erection of the walls. However the curing of the concrete blocks in the factory remains an issue which was observed during collection of the specimens. Curing is the process of maintaining satisfactory moisture content and a favourable temperature in the blocks to ensure hydration of the cement and development of optimum strength (CCI, 2011) something which was ignored in all visited factories.

Lack of proper industrial production expertise by factories has led to series of shortcoming in relevant to former Iraqi Standard ISS of 1987 and modern international standards such as Eurocode. This study has shown shortcomings in density, dimensions, mixtures and comprehensive strength, as well as nonstandard production methods which all related to lack of knowledge, expertise, quality checks, and market responsibilities and accountability.

VI. STUDY RECOMMENDATIONS

This study is conducted on the basis of information and operation available in the production of concrete blocks market and factories. The aim is to provide information to the prospective investors and consumers of regional concrete block factories. It is advised that prior to making a firm decision for investment in the project the investors must verify the various feasibility aspects together along with the requirements relevant to industrial standard of concrete masonry unit production. This needs to become a legal framework for the procurement of plant and machinery and raw materials before they establish a factory.

This is the first research study on cellular concrete blocks conducted in the region. The study shows that none of the monitored factories actually undergone any training or industrial regulatory monitoring system. Their products do not follow any known standards and the product mixtures are prepared using rules of thumbs and trial and error process. None of the factories indicated unannounced visits to collect random sampling of block from their plants. Regulating the concrete block manufacturer via standard production method, quality control, and imposed national building standard building code can promote the following objectives:

1. Increasing the quality of building products.
2. Reducing the cost and waste of materials.
3. Increasing structural safety.
4. Increasing the chances of producing and marketing.
5. Increasing the life space of building.

In the visited factories, the blocks were in open air and not kept in shelters from sun and drying winds therefore the curing process were not controlled. Normally it is recommended that after 24 hours the blocks watered and kept damp for several days to allow the cement to hydrate completely (Steven et al., 2003). The longer the curing process the better is the strength. The blocks should thereafter be completely dried prior delivery to the market for application.

This study strongly recommends the implementation of Eurocode in general and Eurocode 6 (Pluijm, 2009) in particular to regulate the concert block market in the region. Guidelines such as Aggregate Concrete Blocks, A Guide to Selection & Specification (CBA, 2007) are simply available to standardise the production method and ensure the stability, resistance, serviceability, durability and economic feasibility of structure based on long global experience and well-studied standards. All factories need to provide full product description that follows the recommended standard for production process (Collins, 2015). To maintain the validity of regulations in line with changes and developments in the field of industry and science, these recommended national standards will be revised when necessary. A professional and governmental entity needs to ensure that manufacturers have valid professional certificates before they are permitted to operate in the market.

VII. CONCLUSIONS

Laboratory tests using cellular concrete blocks permitted to adequately characterise the block specific market value

properties by specimen testing. Tests on these blocks indicate that the non-standard production methods are associated with irregular market and lack of education and specific requirements to establish and operate concrete block production factories. This paper has made a series of recommendations to tackle the shortcomings and regulate the market in section VI.

This paper concluded that three aspects should be monitored to ensure quality masonry units namely strength, dimensions and water absorption. Ideally, blocks should be regularly tested for strength and mixes and production processes modified if necessary. This needs to randomly be observed and quality checked for safety and improvement of building construction materials which consequently raise the quality and structural safety in the construction industry of the region.

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