Statistical and Experimental Study of Structural Hollow Concrete Blocks Adopting the ACI Mix Design: A Case Study

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ABSTRACT

This study investigates the production of structural hollow blocks bearing load as a masonry unit using statistical regression analysis. Production of blocks that comply with the specification limits of IQS 1077 is a challenge to achieve the appropriate minimum cement content in terms of economic and environmental goals. Data were collected to correlate the normal compressive strength required in the ACI 211.1 mix design with the expected compressive strength within the IQS requirements. Experimental work included preparing hollow blocks using a compress block machine with two curing methods, immersion (normal curing) and spray water (easy and close to factory field production), for 7 days. The recommended block types had a mixture proportion of 1:3.516:2.333 and 1:4.34:2.692 for cement, fine aggregate, and coarse aggregate, consuming cement content equal to 300 kg/m^3 and 260 kg/m^3, respectively, following IQS requirements. Mixture proportions with minimum cost and strength requirements were successfully achieved.

Keywords-load bearing hollow block; ACI 211.1 mix design; SPSS; curing method

I. INTRODUCTION

Load-bearing masonry units are defined according to IQS 1077 as a unit for the construction of walls with the most popular dimensions being length 400±3, width 200±3, height 200± 3, web ≥20, shell ≥20 mm, and classified as [1]:

- Type A: For general use on external or internal walls or internal walls exposed to moisture with minimum average compressive strength of three blocks 7.0 MPa, 6.0 MPa for one block, and absorption of less than 20% at 14 days.
- Type B: For use above ground level in an internal or external wall that is protected from moisture with a minimum average compressive strength of three 5.0 MPa and not less than 4.5 MPa for one block, and absorption of less than 15% at 14 days.

The appearance requirements are [1]:

- The blocks are sturdy and free of cracks or defects that interfere with the proper placement of the block and reduce its durability.
- Faces prepared for cladding shall be of sufficient roughness.
- The exposed face should be free of indentations, cracks, or defects.

There are three types of concrete block units, namely normal, medium, and light in weight, which can be used for both loaded and unloaded walls according to ASTM C90 [2]. The use of sustainable recycling waste material in concrete construction may be important in overcoming waste disposal and reducing pollution [3-5]. The blocks are made of Portland cement, normal or lightweight aggregates, and water, with or without additives [6, 7]. Sustainable block manufacturing using different waste materials is a new technological approach in Iraq and many other countries. Green concrete (eco-friendly) is an inventive way to reduce pollution by using different recycled waste in block structures [8, 9]. This investigation aimed to achieve the required compressive strength of load-bearing units at a minimum cost.

II. STATISTICAL AND EXPERIMENTAL INVESTIGATION

Figure 1 presents the statistical regression analysis method using SPSS after collecting data and then experimenting with blockwork production.

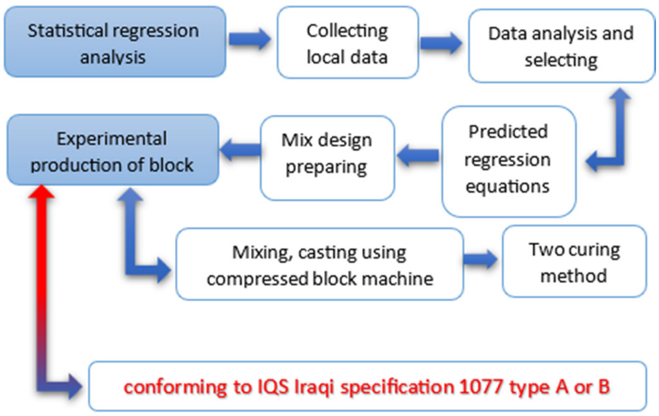

Fig. 1. Investigation diagram.

III. STATISTICAL REGRESSION ANALYSIS

A. Data Collection and Analysis

Table I lists collected data on Load-Bearing Block Units Block (LBU-B) production based on IQS guide 32 [10] and conforming with [1]:

- The production of five block mixtures in [11] used different cement contents. The production of the sustainable block B-380 contained 380 kg/m^3 cement, 20 kg/m^3 nano-silica powder, and 10% plastic waste for the coarse aggregate. B-285 contained 285 kg/m^3 cement, 15 kg/m^3 nano-silica powder, and 10% by volume plastic waste for coarse aggregate. All manufactured blocks complied with IQS 1077 in dimension and absorption type A, except for block mixtures B-200 and B-285, which were of type B.
- In [12], sustainable LBU-B production was achieved by partially replacing with LECA (RL10 and RL 20), waste clay brick (RB10 and RB20), and thermostone blocks in volumes of 10 and 20% of coarse aggregate with a cement content of 300 kg/m^3. All LBU-B manufactured conformed to IQS 1077 in dimension and absorption type A, except the block mixtures RT20 and RL20 that were of type B. Increasing the curing water time from 14 to 28 days, block units of RL20 and RT20 changed from type B to A.
- In [13], the main goal was to produce hollow LBU-B containing sustainable waste from demolished building materials with 300 kg/m^3 cement content. Eight concrete mixtures were adopted: a reference mix, mixtures with 5, 10 and 20% volume replacement for coarse aggregate (AB5%, AB10%, and AB20%), and finally 5 or 10% powder replacement of cement weight by brick or glass powder (PB5%, PB10%, PG5%, PG10%). All hollow LBU-Bs were within the required dimension limits and compressive strength requirements type A, except the block containing 20% clay brick aggregate waste that was of type B but could be converted to type A when the curing time increased from 14 to 28 days.
- In [14], low-cost load-bearing sustainable blocks were produced by replacing natural coarse aggregate with crushed waste from concrete, tiles, or bricks by 10 or 20% by volume. The cement content was 300 kg/m^3 for MR20 and was reduced to 226 kg/m^3 in M15. The samples were labeled C10%, C20%, T10%, T20%, B10%, and B20% for concrete, tile, and brick, respectively. All manufactured blocks were within the dimension requirements of 400×100×100 mm and type A, except M15 and B20% which were of type B but could be converted to A by increasing water curing from 14 to 28 days.

The ACI 211.1 [15] mix design was used to examine the compressive strength and achieve a mixture of good quality.

B. Data Regression analysis

The data presented in Table I were used. Table II presents descriptive statistics for both 14 and 28 days of curing [11-14]. From Figure 2, the results of [11] were excluded due to variance from other studies because of the high required compressive strength that was not needed to produce block type A. Therefore, Table III and Figure 3 present the data that were used for the analysis. Table IV presents the correlation between normal and block compressive strength, which is a high linear relation. So, a linear regression analysis was adopted.

TABLE I. COLLECTED DATA

Ref.	Required compressive strength*	Powder: Aggregate	Mix symbol (as appears in the respective study)	Compressive strength (MPa)			
				Normal concrete		LBU-B	
				14-days	28-days	14-days	28-days
[11]	30 MPa	1:4.3	B-400	41.98	49.71	9.65	11.98
		1:5.8	B-300	37.43	43.71	7.11	9.33
		1:8.7	B-200	34.35	40.15	5.34	6.84
		1:4.2	B-380	46.25	56.12	6.57	8.62
		1:5.6	B-285	50.15	59.85	5.86	7.64
[12]	20 MPa	1:5.7	R-300	22.5	26.8	7.4	8.2
		1:5.64	RB10	22.9	27.3	7.6	8.4
		1:5.24	RB20	21.4	25.5	7.1	7.8
		1:5.62	RL10	21.6	25.8	7.2	7.9
		1:5.37	RL20	20.5	24.5	6.8	7.5
		1:5.55	RT10	21.3	25.4	7.0	7.7
		1:5.35	RT20	20.3	24.2	6.6	7.3
[13]	20 MPa	1:5.75	Reference	20.8	26.7	7.4	8.2
		1:5.69	AB5%	21.5	27.7	7.6	8.5
		1:5.63	AB10%	21.2	27.1	7.5	8.4
		1:5.52	AB20%	20	24.6	6.9	7.5
		1:5.75	PB5%	21.9	29.3	7.9	8.9
		1:5.75	PB10%	21.3	28.1	7.8	8.7
		1:5.75	PG5%	21.1	27.1	7.6	8.6
		1:5.75	PG10%	21	27	7.5	8.4
[14]	20 MPa	1:5.78	MR20	19.5	23.8	7.4	7.8
		1:6.73	M15**	15.5	18.8	6.5	7.1
		1:5.73	C10%	20.5	25.8	7.6	7.85
		1:5.69	C20%	21.1	26.5	7.8	7.95
		1:5.72	T10%	19.5	24.2	7.4	7.5
		1:5.67	T20%	19.6	24.6	7.1	7.3
		1:5.68	B10%	19.4	24.2	7.0	7.2
		1:5.59	B20%	18.0	22.5	6.6	7.0

*The required compressive strength adopting the ACI 211.1 is equal to 20 MPa and w/c with a slump range of 25-50mm with a reduction of water not more than 5% to produce a dry to semi-dry mixture.

TABLE II. DESCRIPTIVE STATISTICS FOR ALL CURING AGES (14 AND 28 DAYS) [11-14]

Compressive strength	Amount of data	Min.	Max.	Mean	St. dev.	Variance
Normal	56	15.50	59.85	27.1357	9.86732	97.364
Block	56	5.34	11.98	7.6418	.97331	.947

TABLE III. DESCRIPTIVE STATISTICS FOR ALL CURING AGES (14 AND 28 DAYS) [11-14]

Compressive strength	Amount of data	Min.	Max.	Mean	St. dev.	Variance
Normal	46	15.50	29.30	23.0413	3.14993	9.922
Block	46	6.50	8.90	7.5870	0.57266	0.328

TABLE IV. CORRELATION STATISTICS FOR ALL CURING AGES (14 AND 28 DAYS) [11-14]

	Compressive strength	Block	Normal
Std. cross-product	Block	1.000	0.997
	Normal	0.997	1.000
N	Block	46	46
	Normal	46	46

C. *Statistical Regression Model*

The linear regression model is presented in Table V with histogram and normal P-P plots in Figures 4 and 5, respectively. The model with the best properties is presented in Tables VI and VII, which is the recommended model.

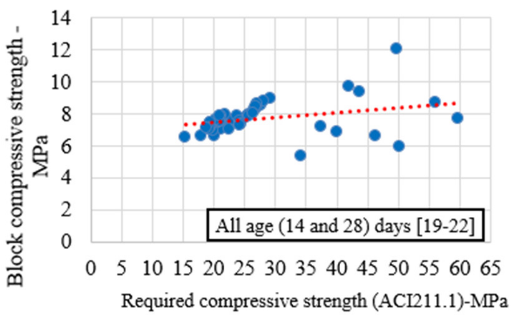

Fig. 2. Required and block compressive strength for all data collected [11-14].

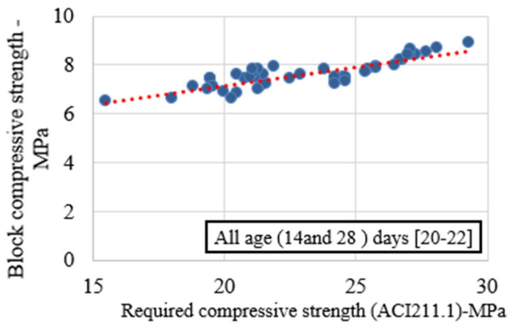

Fig. 3. Required and block compressive strength for data collected from [11-14].

The equation of the recommended model is:

$$Required\ compressive\ strength(block) = 0.326 \times Normal\ compressive\ strength$$

TABLE V. REGRESSION MODEL USING SPSS

Coefficients- model					
Model-regression	**Unstandardized coefficients**		**Standardized-coefficients**	**t**	**Sig.**
	B of the model	**Std. error of the model**	**Beta model**		
Normal compressive strength	0.326	0.004	0.997	81.675	0.000

TABLE VI. REGRESSION ANOVA USING SPSS

Model	**Sum of squares**	**df**	**Mean square**	**F-calculated**	**Sig.**
Regression	2644.764	1	2644.764	6670.813	0.000
Residual	17.841	45	0.396		
Total	2662.605	46			

TABLE VII. REGRESSION ANALYSIS USING SPSS

R	**R^2**	**Std. error of estimate**	**Change statistics**				
			R^2 change	**F- change**	**df_1**	**df_2**	**Sig. F-change**
0.997	0.993	0.62966	0.993	6670.8	1	45	0.000

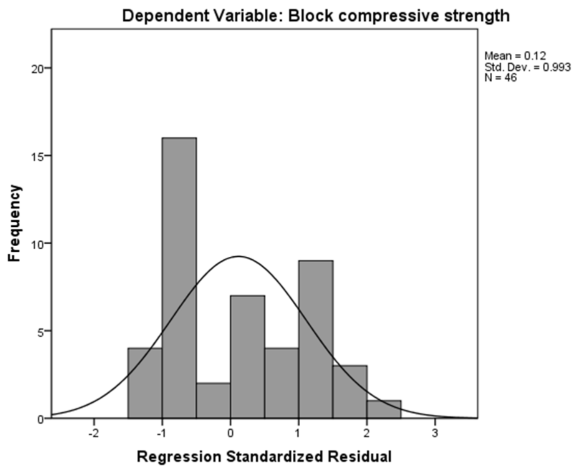

Fig. 4. Histogram of the regression standardized model.

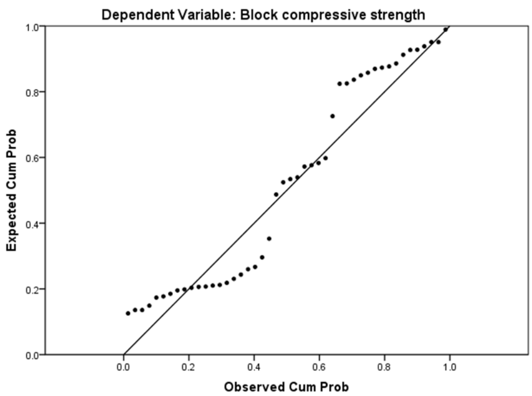

Fig. 5. Normal (P-P plot) of the regression analysis model.

IV. EXPERIMENTAL WORK

A. Collecting Materials

The mixture-material content of the block using Portland cement (OPC-class R 42.5) conformed to IQS No.5 [16] as shown in Table VIII. The fine-aggregate with FM = 2.98 and single-size crushed-coarse-aggregate properties along with the grading test are presented in Figures 6 and 7, respectively, conforming to IQS No.45 [17]. The water (tap) for curing and mixing conforms to the IQS 1703 [18].

TABLE VIII. CEMENT PROPERTIES (OPC: CLASS CEM I R 42.5).

	Oxide-results (%)				**C_3A-buge equation (%)**	**Soundness (%)**	**Blaine- surface (m^2/ kg)**	**Vicat's-setting time (min)**		**Comp. strength (MPa)**	
	MgO	**SO_3**	**LOI**	**IR**				**Initial**	**Final**	**2 days**	**28 days**
OPC class R 42.5	4.35	2. 45	1.35	0.62	7.10	0.12	386	165	260	27.5	45.2
IQS No.5	≤ 5.0	≤ 2.8	≤ 4.0	≤ 1.50	>3.5	≤ 0.8	≥ 280	≥ 45	≤ 600	≥ 20	≥ 42.5

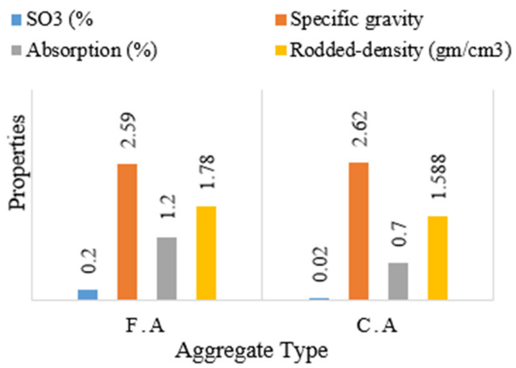

Fig. 6. Properties of coarse and fine aggregate conforming to IQS No. 45.

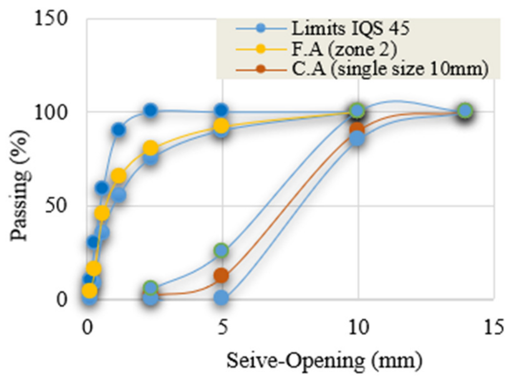

Fig. 7. Grading by sieve analysis of fine (F.A) and coarse (C.A) aggregates conforming to IQS No.45.

B. Mixture design

ACI 211.1 was implemented for the concrete mixture to be used in the production of load masonry units. The predicted compressive strength of load-bearing hollow blocks was calculated using the adopted model:

$$CompressiveStrengthOfBlock = 0.326 \times RequiredCompressiveStrength(ACI\ 221.1).$$

So, the compressive strength required for blocks of type A and B was approximately 20 MPa and 15 MPa, respectively. Figure 8 presents the mixture content. A slump range of 25-50mm and a water reduction of less than or equal to 5% was used to produce a dry to semi-dry mixture.

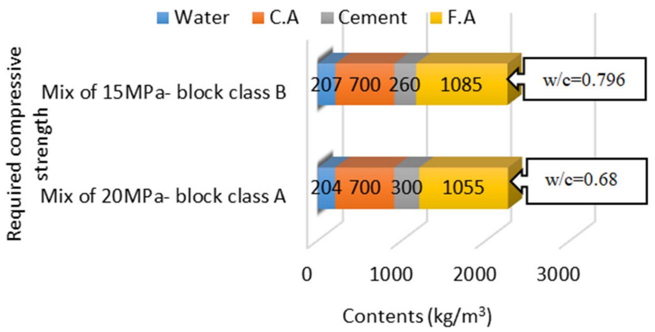

Fig. 8. Materials' content for concrete for normal and spray curing methods.

C. Production and Testing Block Units

After mixing the materials according to ASTM C192 [19], the mixture was fed to an automatic block machine's basin with dimensions of 200×200×400 mm as a compressed hollow block. Hollow refers to containing one or more hollows or holes, and the hollow volume is between 25-50% of the total mass volume. Then, the blocks are covered by a wet plastic sheet for approximately 24 hrs. Then, they are cured for 14 or 28) days according to:

- Normal curing adopting ASTM C192/C192M-16a [19].
- Spray water two times per day at 8 am and 2 pm for 7 days.

Finally, the specimens were tested after 14 and 28 days according to:

- Compressive strength and absorption test adopting the Iraq guide No. 32 [10] for blocks.
- Compressive strength for normal concrete cylinders according to ASTM C39/C39M-15a [20].

Figure 9 presents the production of concrete masonry unit blocks.

V. RESULTS AND DISCUSSION

The dimensions of all produced hollow blocks (masonry hollow units) for thickness (shell and web), length, width, and height at 14 days were according to Iraq guide No. 32 [10] within the limits of IQS 1077 [1]. Table IX shows the properties, including absorption and compressive strength, at 14 and 28 days for the normal concrete and hollow units. Figures 10 and 11 present the compressive strength and absorption results of the blocks at 14 and 28 days, respectively. The experiments proved that less cement content can be used with less cost. More strength can be noticed at 14 days as recommended in IQS 1077 [1]. It should be noted that increasing the curing time from 14 to 28 days led to improved block quality, with more hydration time, and improved the densification of the concrete structure and dry density [6].

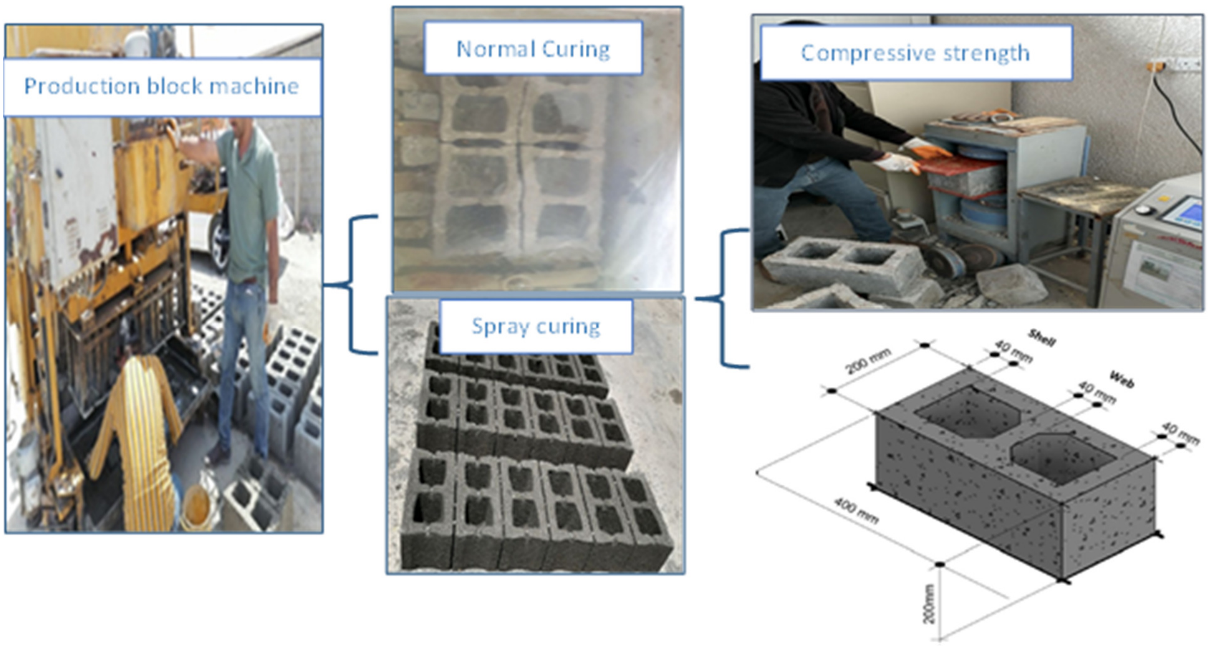

Fig. 9. Production of concrete masonry units (block dimensions: 400×100×100 mm).

TABLE IX. PROPERTIES OF CONCRETE MASONRY UNITS AND NORMAL CONCRETE MIXTURE

Mixture	Absorption (%) 14-days	Absorption (%) 28-days	Compressive strength test (MPa) 14-days Type	14-days Each block	14-days Avg. 3-block	14-days Avg. 3-cylinder	28-days Type	28-days Each block	28-days Avg. 3-block	28-days Avg. 3-cylinder
	Avg. 3- block									
B-20-U Under-water	7.5	5.5	A	7.5	7.46	17.8	A	7.8	7.73	23.5
				7.2				7.5		
				7.7				7.6		
B-20-S Spray-water	10.1	8.5	A	6.8	7.10	16.6	A	7.2	7.46	22.6
				7.1				7.6		
				7.4				7.6		
B-15-U Under-water	11.5	9.2	B	5.5	5.43	14.2	B	6.2	5.60	17.5
				5.2				5.2		
				5.6				5.4		
B-15-S Spray-water	12.5	10.2	fail	5.1	4.80	12.5	B	4.8	5.07	15.6
				4.4				5.1		
				4.9				5.3		

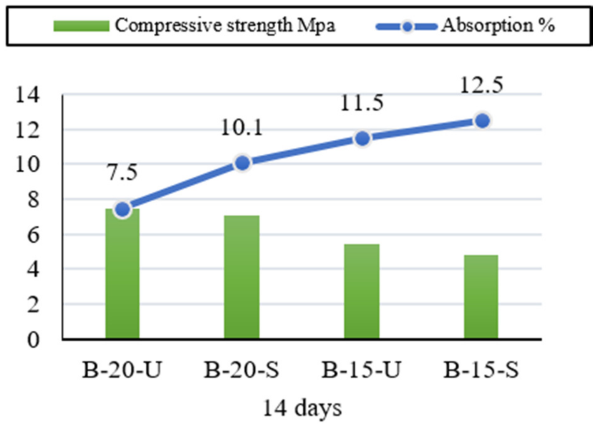

Fig. 10. Compressive strength and absorption of blocks at 14 days.

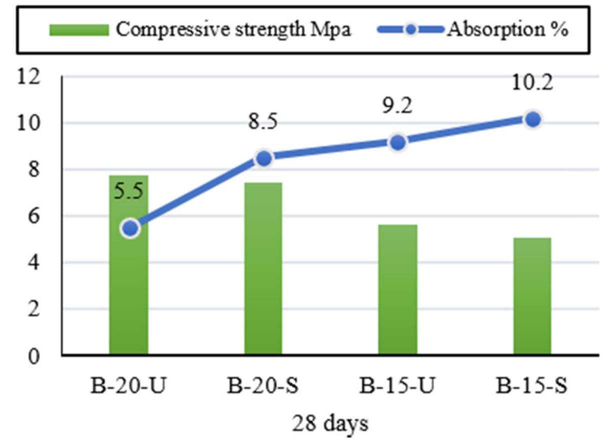

Fig. 11. Compressive strength and absorption of the block at 28 days.

VI. CONCLUSIONS

This study demonstrated the ability to produce type A load-bearing hollow units (blocks) with a mixture proportion of 1:3.516:2.333 cement, fine aggregate, and coarse aggregate, respectively, containing 300 kg/m^3 cement and type B with a mixture proportion of 1:4.34:2.692 containing 260 kg/m^3 cement. This study adopted a statistical regression equation with a high R^2 (0.993) to predict compressive strength. High compressive strength was developed at 14 days with water spray curing in a field factory. The increase of the water curing duration from 14 to 28 days improved block quality and converted it from failed to acceptable for the case of the B-15-S mixture.

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