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Structural behavior of lightweight interlocking brick system

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Abstract. Lightweight interlocking brick is one alternative to replace conventional clay brick through combustion. This study is related to the design of the proportion of interlocking light brick mixtures as well as concrete sand and foam agent in various percentages and found the optimal percentage of foam agent by testing cylindrical specimens casted for 28 days compressive strength and finally testing each others lightweight brick shear strength lock in full scale model.The final report provided the results of investigative experiments in which compressive strength, water absorption and density were investigated using the optimal percentage of the proportion of foam agent, sand, cement, and aggregate mixture. In conclusion, The results obtained from this experiment are the compressive strength lightweight interlocking brick with the addition of 0% fiberglass of 2.27 MPa,1% fiberglass addition of 2.88 MPa, 3% fiberglass addition of 2.91 MPa, the addition of fiberglass 6% of 2.88 MPa, addition of 9% fiberglass of 2.94 MPa and flexural lateral compressive strength test at a maximum load of 11,084 kg/cm^2 with a deflection of 6,405 mm. Horizontal shear test results are 1,218 kg/cm^2 and for diagonal shear testing is 0.398 kg/cm^2. The total production cost of interlocking light bricks is IDR 786,000 per cubic meter more expensive than normal light bricks.

1. Introduction

Nowadays, lightweight concrete are commonly used in precast and pre stressed components, Specifically speaking, while lightweight concrete compels higher costs compares to normal weight concrete, structures may yet have lower costs as a results of the reductions in dead weight, foundation sizes and costs, and consumed reinforcement bars [1].

Foam concrete is a very fluid, lightweight cellular concrete fill material, produced by blending a cement paste (the slurry or mortar), with a separately manufactured, preformed foam. The density of foam concrete is determined by the ratio of foam to slurry and densities range typically between 300 and 1600 kg/m^3. Foam concrete is created by uniform distribution of air bubbles throughout the mass of concrete. The foam cells must have walls, which remain stable during mixing, transportation, pumping and placing of fresh concrete. The cells, or bubbles are discrete and range in size between 0.1 and 1 mm. Foam concrete is a free flowing and can be placed without compaction [2].

Damage to wall construction that is dominated by red brick pairs usually occurs frequently, due to damage due to large shear stresses or the combination of flexural stresses during earthquake events. The burden of an earthquake can provide horizontal loads on building so that, they often cause damage to structural and non structural components as well. Walls in residential homes are usually made of concrete brick pairs made from a mixture of cement, sand and water with certain levels [3].

In this study, the composition of test specimens in the form of interlocking lightweight bricks and lateral shear and flexural testing were carried out, and to compare the strengths between ordinary light bricks and interlocking bricks which were subjected to prior research in the laboratory.

2. Literature Review

2.1. Lightweight bricks

Bungunaen, Hunggurami and Muskanan, 2014 researched substitution influence of lime stone to the sand forward the compressive strength and water absorption in the CLC light brick quoting words from Ngabdurrochman, 2009 in the Lightweight Concrete Technology books describe lightweight brick is a porous brick that has a density lighter than bricks in general. Lightweight brick density between 600 – 1600 kg/m3 with strength depends on the composition of the mix design [4]. The modulus of elasticity of light brick 17500 MPa with bond strength (μ) 0.41 MPa [5].

Taufik, Kurniawandy and Arita, 2017 researched lightweight bricks made by adding foam agent by CLC method described Celular Lightweight Concrete (CLC) light brick is one type of light concrete, producd by inserting air bubble granules in a brick mortar mixture. CLC consists of sand, cement, water and foam produced from a mixture of water and foam agent [6].

2.2. Interlocking block

Thanoon, Alwathaf, Noorzaei, Jafar and Abdulkadir researched analysis of interlocing mortarless hollow concrete block system to axial compression loads using FEM inform interlocking mortarless load bearing load block systems are different from conventional mortar masonry system in which the mortar layers are eliminated and instead the block units are interconnected through interlocking protrusions and grooves. The behaviour of this system is affected highly by the behaviour of the mortarless (dry) joint in both elastic and inelastic stages of loading. The geometric imperfection of the bed blocks is an important factor influences the structural behaviour of the mortarless masonry system. Hence, modelling of mortarless joint plays a significant role in the overall simulation of the system [7].

Philip, 1934 in his invention about Interlocking Building Brick elucidate Another object is to provide interlocking building bricks capable of simplifying and improving the construction of locking corners for a Wall and the like, in which the bricks in each course are firmly interlocked at the corners, with adjoining courses alternating for the production of a va riety of Ornamental effects at the exterior of the Wall [8].

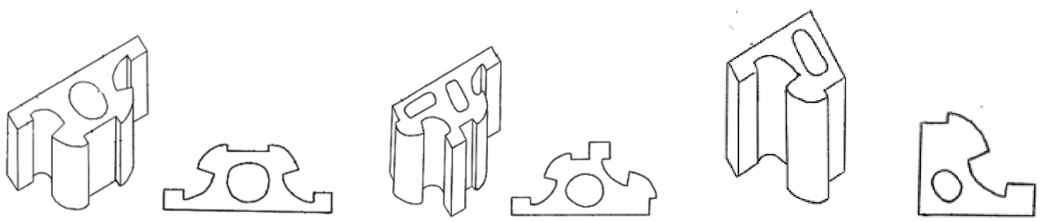


Figure 1. The Lightweight Brick Model Interlocks.
Source: Boot, D.AL, 2003.

2.3. Foam agent

Hamad, 2014 researched attention to concrete and autoclaved concrete. And his conclude a compressive strength of foamed concrete can be developed reach to structural strength compared with autoclaved aerated concrete. Hamad described The foam agent used to obtain foamed concrete. It is defined as air entraining agent the foam agent is the most essential influence on the foamed concrete. The foam agents when added inti the mix water it will produce discrete bubbles cavities which become incorporated in the cement paste. The properties of foamed concrete are critically dependent upon the quality of the foam. Foam agent can be classified according to types of foaming . i) Synthetic-suitable for densities from 1000 kg/m^3 and above. ii) Protein-suitable for densities from 400 kg/m^3 to 1600 kg/m^3 [9].

Figure 2. Foam agent.

2.4. Fiberglass

Aditiya, researched Glass fiber composites and polypropylene construction, application for alumunium boat explain Glass-reinforced plastic (GRP), a reinforced polymer. This polymer is made of plastic material which is reinforced by fine fibers made of glass. Fiberglass or glass fiber is liquid glass that is stretched into thin fibers with a diameter of about 0.005 mm - 0.01 mm. This fiber can be spun into yarn or woven into fabric, which is then impregnated with resin so that it becomes a strong and corrosion-resistant material [10].

Figure 3. Fiberglass.
Source: Aditiya [10].

2.5. Flexural strength

Hugh and Roger, in the Physics University Books elucidate Flexural Strength is the strength to resist forces or withstand both dead and living loads. SNI 03-4154-1996 describe flexural strength of a lightweight brick is the ability of a concrete beams placed on a placement to hold the forces perpendicular to the axis of the test object until the test object begins to collapse [11].

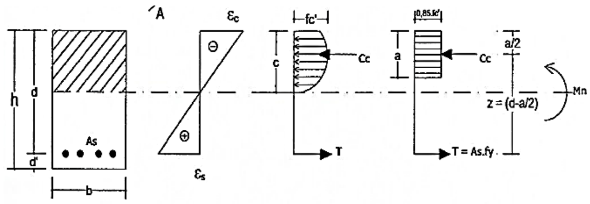


Figure 4. Strain and stress diagrams in a balanced state
Source: Rasidi N in 2015.

On the under reinforced condition, steel reinforcement has been yield (fs=fy), so that **Equation 1**.

$$Cc = Ts$$
$$Cc = 0.85 \cdot f'c \cdot a \cdot b \tag{1}$$

And the section moment can be calculated with **Equation 2**.

$$Mn = Ts\ (d\text{-}½a) = Cc\ (d\text{-}½a) = 0.85\ .\ f'c\ .\ a\ .\ b\ (d\text{-}½a) \quad (2)$$

Where:
Cc = Concrete Compressive Force (kNm)
Ts= Reinforcement steel Tensile Force (kN)
f'c= Concrete Stress (MPa)
a = Beam lenght (mm)
b = Beam width (mm)
Mn = Actual nominal moment (kNm)
d = Efective length of beam section (mm)

According to SNI 03-4154-1996, flexural strength calculations can be calculated using **Equations 3**. [12]

$$Flt = 3.P.L/2.b.d^2 \quad (3)$$

Where:
Flt = Flexural strength (MPa)
P = Maximum load (N)
L = Span length (mm)
b = Width of test specimen (mm)
d = Test object height (mm)

2.6. Shear strength

McCormac and Brown, in Design Reinforced Concrete Book convey a great deal of research has been done on the subject of shear and diagonal tension for nonhomogeneous reinforced concrete beams, and many theories have developed. Inclined cracks can develop in the webs of reinforced concrete beams, either as extension of flexural cracks or occasionally as independent cracks [13].

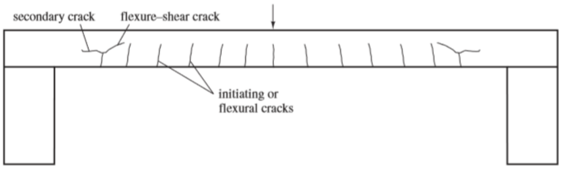


Figure 5. Flexural-Shear Cracks.
Source: McCormac and Brown [13].

Romly, researched determine the effect of the brick immerse time in water against the compressive strength, adhesion strength and diagonal strength of masonry wall phrase examination of the brick pairs shear strength is the ability to accept the maximum shear load from the bond between the mortar and the brick [14].

SNI 03-4166-1996, shear strength testing of masonry is carried out with arranged test specimens. The loading speed must be constant evenly and can be adjusted so that the loading motion is between 15- - 210 N/mm/minute. Horizontal Shear Strength calculations on the wall can be used **Equation 4** [15].

$$fvh = Pu\ /\ 2.b.h \quad (4)$$

And Diagonal Shear Strength calculations can be used **Equation 5**.

$$f_{vd} = \frac{0{,}707\ .\ P_u + W}{A} \text{x (1-μ)} \quad (5)$$

Where :
fvh = Bond Strength of Specimen (N/mm^2)
fvd = Bond Strength of Specimen (N/mm^2)

Pu = Maximum Load (N)
b = Width of Test Specimen (mm)
d = Test Object Height (mm)
A = Test Object Cross Sectional Area (mm^2)
μ = Friction Coefficient (0.3)

3. Methodology
The research flow is shown on **Figure 6**.

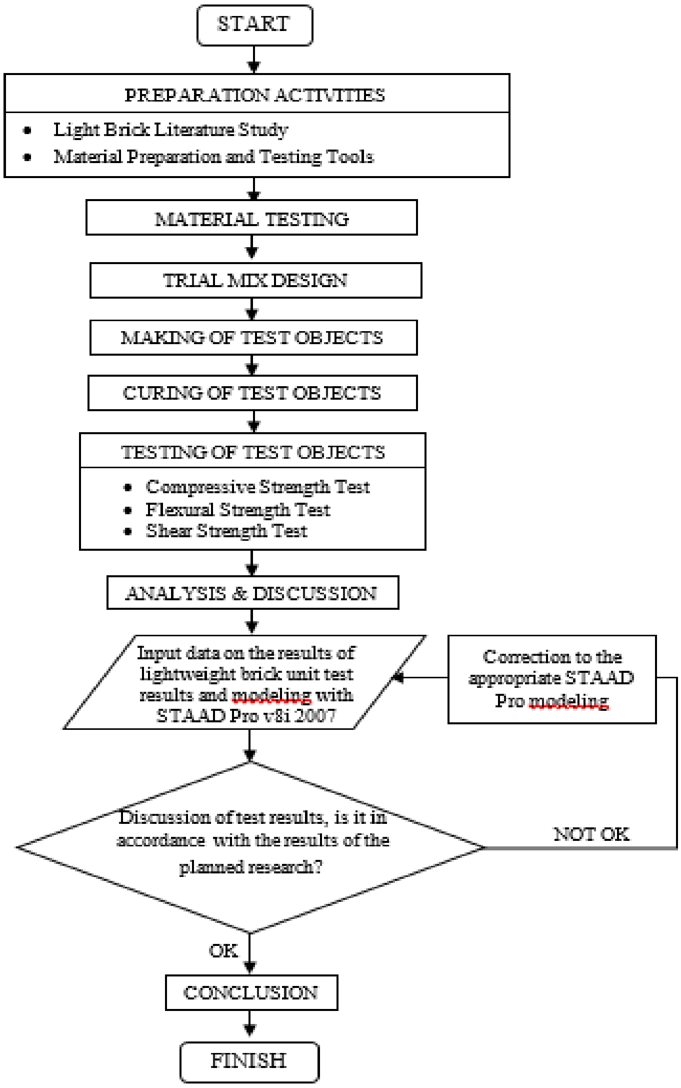


Figure 6. Flow chart diagram.

3.1. Preparation
Preparation that did in this research is begun by conducted a study of journal literature and references about lightweight interlocking bricks, then preparation of materials, tools and samples, and make mix design calculation.

3.2. Working phase
After all of preparation have finished, the next step will be done on working phase. In this phase, the research begins with sample producing, sample treatment, and testing sample. The testing are

compressive strength, flexural strength and shear strength test, then making modelling from lightweight interlocking brick using software of structure to compare the test result and the analysis result.

In this study the addition of the percentage of the independent variable is fiberglass, with the percentage of the addition of fiberglass to the composition of a light weighted brick mixture of 0%, 1%, 3%, 6%, and 9% of the weight of cement. Whereas the dependent variable is the percentage composition of sand, cement, water and foam agent. For the last variable is the control variable, namely the implementation of making the same test object, material, place of research and the same tools used.

This scientific article writing is done with analyzing data from the test result of lightweight interlocking bricks, the data that analyzed are figure, graph, modelling, and calculation. Then from the analysis result which have done, therefore can be concluded.

4. Results and discussion

4.1. Mix design

Foam agent and fiberglass variation mix design for lightweight concrete cylinder specimens intended for compressive strength test can be seen in **Table 1**.

Table 1. Foam agent and fiberglass variation mix design for one sample.

Material	**Mixed Composition**					**Unit**
	0%	**1%**	**3%**	**6%**	**9%**	
Cement	7,5	7,5	7,5	7,5	7,5	Kg
Sand	15	15	15	15	15	Kg
Water	4	4	4	4	4	Liter
Level of Foam Agent	0,8	0,8	0,8	0,8	0,8	Liter
Foam Agent	20	20	20	20	20	ml
Fiberglass	-	0,075	0,225	0,450	0,675	Kg

And a mix design for lightweight interlocking brick per m^3 for flexural strength and shear strength test can be seen in **Table 2**.

Table 2. Material requirements per m^3.

Level of *fiberglass* (%)	Level of *foam agent* (liter)	Cement (kg)	Water (liter)	Sand (kg)	*Foam Agent* (ml)	*Fiber glass* (kg)
3%	0,8	187	93,5	374	20	5,610

4.2. Compressive strength of lightweight concrete with foam agent and fiberglass

In this research have tested relation between compressive strength and the weight of lightweight concrete with percentage of addition fiberglass 0%, 1%, 3%, 6% and 9%, on 28th days. The result graph of concrete compressive strength test is shown in **Figure 7**.

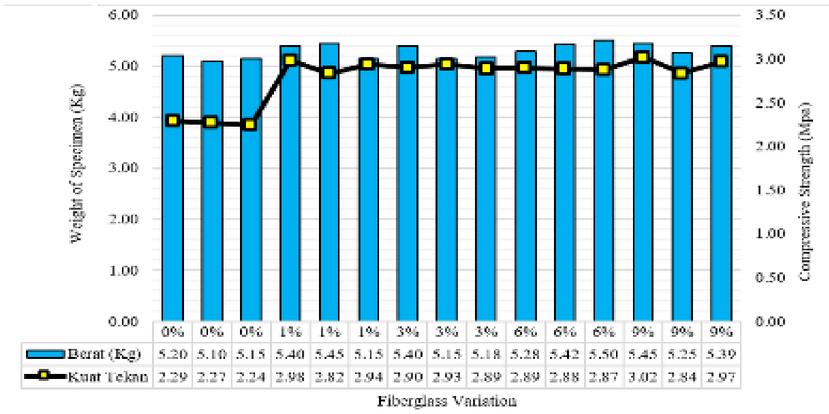


Figure 7. Graph of the relationship between compressive strength and weight of the test specimen.

4.3. Compressive strength of lightweight interlocking bricks with fiberglass variation

In this research, the correlation between fiberglass influence on the variation of 3% on compressive strength of light brick is shown in **Figure 8.**

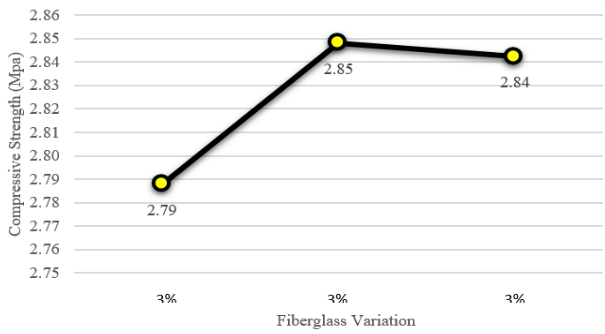


Figure 8. Fiberglass variation and compressive strength of concrete relation.

Relation between concrete sample weight and fiberglass percentage variation 3% is shown in **Figure 9.**

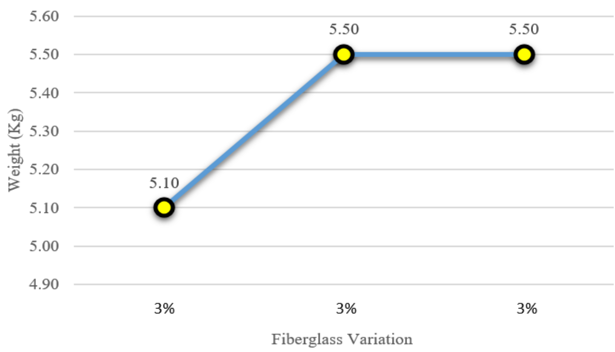
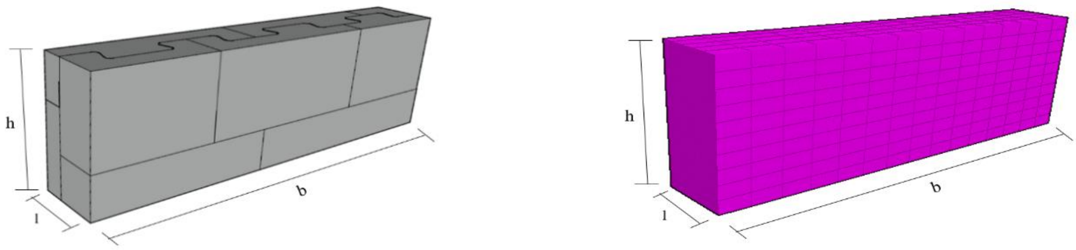


Figure 9. Fiberglass variation and Weight of concrete relation.

4.4. Lightweight interlocking brick modelling
The lightweight interlocking brick pair is modelled in the form of a wall to calculate the results of lateral bending tests that occur. Lateral bending tests are carried out to determine the magnitude of the resistance of the wall of the lightweight brick pair in bearing in bearing the load. In addition, modelling in shear testing is also to determine the amount of wall resistance in receiving shear loads from earthquakes or other things. For idealization of modelling is shown in **Figure 10.**



(a) (b)

Figure 10. Structural Modelling and Loading of Lightweight Interlocking Bricks Wall, a) Modelling with SketchUp Application, b) Modelling with StaadProVi7 Application.

4.5. Structural loading on lightweight interlocking brick wall
The loading used in this structural analysis based on the research that has loaded in bending test in the form of nodal load on determined area with selfweight factor value is 1.005 and then combined with P load. Structural loading modelling is shown in **Figure 11.**

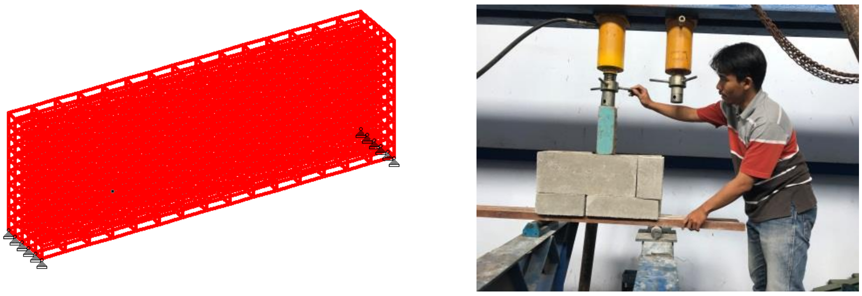
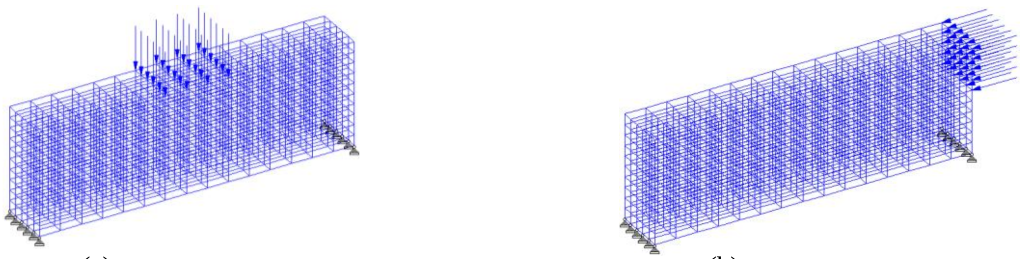


Figure 11. Dead Load on the Lightweight Interlocking Brick Wall in STAAD Pro modelling.

The dead load of lightweight concrete slab is done by putting selfweight factor in -1,005 on load command selfweight to Y axis, negative because purposed to be opposite on Y axis or downward on lightweight concrete slab modelling.



(a) (b)

Figure 12. P load on the Lightweight Interlocking Brick Wall in STAAD Pro modelling, a) Load P from Above, b) Load P from Side.

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P load on the light brick wall is obtained from the test data that has been done previously. P load starts from 0 KN for every load of 0.5 KN until the limit is failure on the test specimen.

4.6. Results of lateral bending analysis on solid elements of lightweight interlocking brick walls

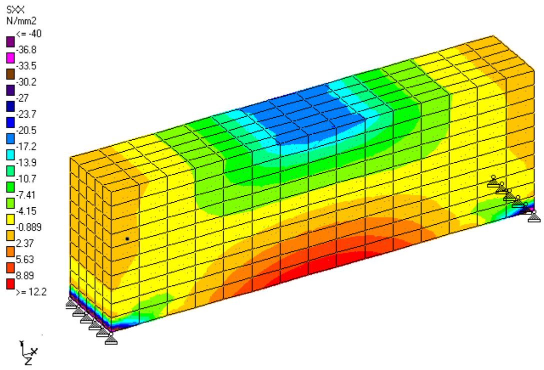


Figure 13. The Results of the Test Object Modelling Receive a P Load from Above (Bending Load).

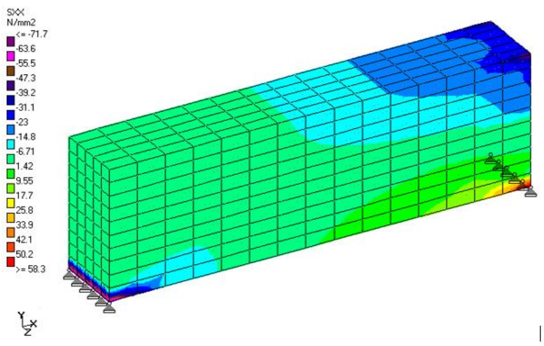


Figure 14. The Results of the Test Object Modelling Receive a P load from Side (Shear Load).

In Figure 13 the result is that the light brick wall is connected to receive a maximum lateral bending load at a value of 12.2 N/mm^2 and in Figure 14 the results are obtained from the modelling of the light brick wall related test object to receive the maximum shear load at a value of 58 , 3 N/mm^2.

4.7. The analysis of lightweight interlocking brick wall flexural strength and shear strength

Calculation of lateral flexural testing on wall specimens is formulated based on SNI 03-4154-1996 on testing flexural strength of concrete with a simple test beam which is centered directly and Calculation of lateral flexural testing on wall specimens is formulated based on SNI 03-4166-1996 concerning testing of shear strength of masonry walls shown in the **Figure 15.**

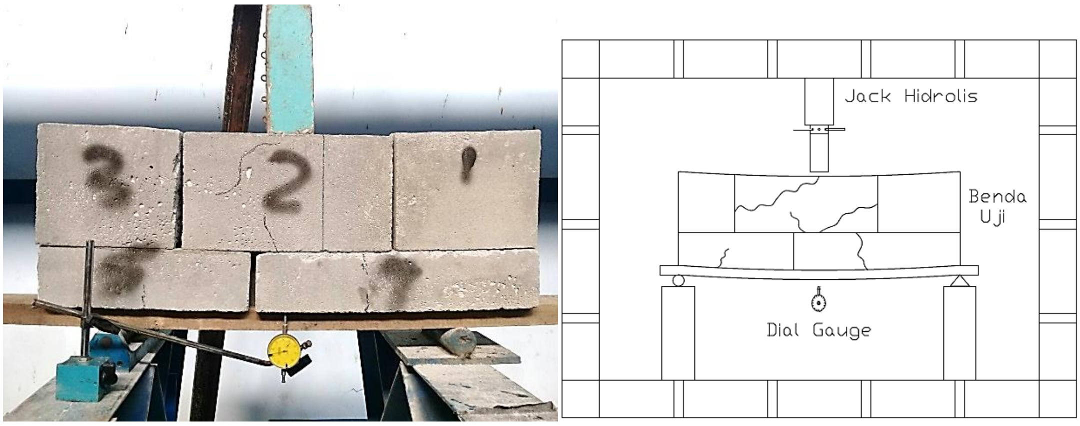


Figure 15. Flexural strength testing of lightweight interlocking brick wall.

Table 3. The result of flexural strength testing of lightweight interlocking brick wall.

Description	Length (l)	Width (b)	High (d)	Load (P)	Lateral bending		Average	Deflection	Average
	(mm)	(mm)	(mm)	(N)	(N/mm²)	(Kg/cm²)	(Kg/cm²)	(mm)	(mm)
Test specimen 1	910	150	300	10000	1,011	10,310	11,084	4,790	6,405
Test specimen 2	910	150	300	11500	1,163	11,857		8,020	

Table 3 shows the average value of lateral flexural strength of 11,084 kg/cm^2 with deflection value of 6.045 mm.

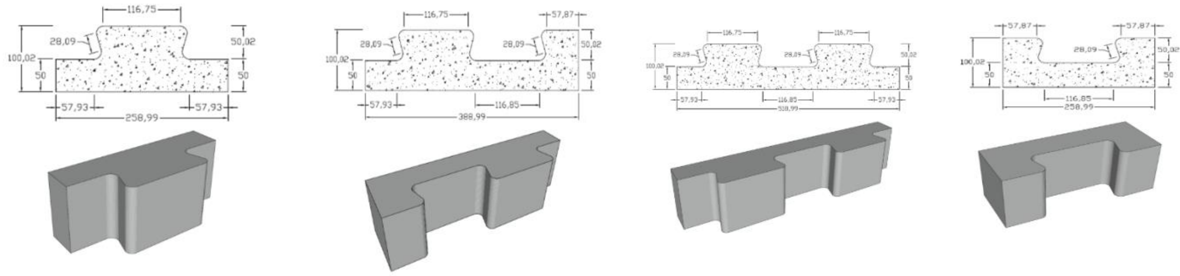
Table 4. The result of shear strength testing of lightweight interlocking brick wall.

Description	Length (l)	Width (b)	High (d)	Load (P)	Horizontal Shear Strength		Average	Diagonal Shear Strength		Average
	(mm)	(mm)	(mm)	(N)	(N/mm²)	(Kg/cm²)	(Kg/cm²)	(N/mm²)	(Kg/cm²)	(Kg/cm²)
Test specimen 1	910	150	300	10000	0,111	1,133	1,218	0,036	0,370	0,398
Test specimen 2	910	150	300	11500	0,128	1,303		0,042	0,426	

Table 4 shows the average value of the horizontal shear strength test is 1,218 kg/cm^2, while the average value of the diagonal shear strength test is 0,398 Kg/cm^2.

4.8. Modelling result lightweight interlocking brick

In this lightweight brick modelling it uses 2 software assistance in the form of image-based software namely AutoCAD and SketchUp. In this light brick modelling, there are 4 types that will be used shown in **Figure 16**.



(a) (b) (c) (d)

Figure 16. Light Brick Dimension Modelling, a) Type I (26 cm x 10 cm x 20 cm), b) Type II (39 cm x 10 cm x 20 cm), c) Type III (52 cm x 10 cm x 20 cm), d) Type IV (26 cm x 10 cm x 20 cm).

4.9. Cost for making 1 m3 of lightweight interlocking brick

Price calculation here intends to get a fair sale price on a light brick, namely the production price plus transportation costs and profits. The selling price is then compared to the selling price of hebel lightweight bricks on the market. A comparison of the prices of light bricks and light interlock bricks is shown in the **Table 5**.

Table 5. Comparison of the fair price of selling lightweight brick related to the results of research and prices on the market

No.	Lightweight Brick Type	Prices on The Market per m^3
1	Lightweight Interlocking Brick	IDR 786.000,-
2	Hebel Lightweight Brick	IDR 780.000,-
3	Voscon Lightweight Brick	IDR 650.000,-

5. Conclusion

- Based on the results of the compressive strength test of lightweight interlocking bricks, the average compressive strength is obtained with the addition of 0% fiberglass of 2.27 MPa, 1% fiberglass addition of 2.88 MPa, 3% fiberglass addition of 2.91 MPa, the addition of fiberglass 6% of 2.88 MPa, addition of 9% fiberglass of 2.94 MPa. From some of the test specimens above, it can be concluded that variations in the addition of 3% fiberglass can be used for lightweight interlocking brick mixture because it has a planned specific gravity of 600 - 1000 kg/m^3, but for compressive strength values do not meet the planned compressive strength values, namely 5 MPa.
- Lateral flexural test results on lightweight interlocking brick associated with the addition of 3% fiberglass variation with a length of 91 cm, width 15 cm and height 30 cm obtained the maximum lateral bending value on the lightweight brick pair specimens of 12.2 N/mm^2 with deflection values of 6.405 mm and for the value of the shear strength of 58.3 N/mm^2.
- Based on an analysis of the calculation of production costs on this lightweight interlocking brick, a production cost of IDR. 786,000 per m^3. This price is a little more expensive than the hebel lightweight bricks on the market, but these lightweight bricks are still worth selling on the market.

Acknowledgments

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