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Investigation of New Bricks (Sand Lime Bricks With Polystyrene and Gypsum Addition)

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دراسة لنوع جديد من الطوب الجير الرملي بإضافة البولي ستايرين والجبس

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Abstract

The main drawback of lime materials is absorbing water easily, therefore causing fluorescence when not exposed to air. In addition, very heavy weight and rough surface of bricks may cause mold growth. Research done in this area has always focused on durability and strength. The challenge of modern and new requirements, the need for sustainable low-cost buildings to host people, and the lack of knowledge in this area justify the need for more research to be focused on the strength, lightweight bricks, and absorption capacity of the sand-lime bricks. The use of polystyrene has many advantages in construction materials. This study presents the results of the experimental investigation that was carried out to find the optimum mix percentage of new bricks. Brick specimens of size 150 *mm*×150 *mm*×150 *mm* were cast for different mix percentages of polystyrene, gypsum, lime, and sand. The results showed the variation of compressive strength for different mix proportions of the mentioned materials. The compressive strength, absorption capacity, and thermal insulation of the newly produced bricks with optimized composition under various brick-forming presses were determined. The results of this study suggested that it was possible to produce good quality lightweight non-fired structural bricks compared with cement bricks.

Keywords: *Bricks; Compressive Strength; Lime; Gypsum; Polystyrene.*

الملخص

العيب الرئيسي لمواد الجير هو امتصاصها الماء بسهولة، ويسبب ذلك وميضاً عندما لا تتعرض للهواء. إضافة إلى ذلك، الوزن الثقيل جدا والسطح الخشن للطوب المصنع منها، الأمر الذي قد يسبب نمو العفن. وقد ركزت البحوث التي أجريت في هذا المجال دائما على المتانة والقوة. إن التحدي المتمثل في المتطلبات الحديثة والجديدة، والحاجة إلى مباني منخفضة التكلفة ومستدامة لمتطلبات الناس، بالإضافة إلى نقص المعرفة في هذا المجال تبرر الحاجة إلى مزيد من البحوث التي تركز على قوة الطوب خفيف الوزن وسعة امتصاص طوب الرمل الجيري. لذا فإن استخدام البولي ستايرين له العديد من المزايا في مواد البناء. تقدم هذه الدراسة نتائج التحقيق التجريبي الذي تم إجراؤه لإيجاد النسبة المثلى لخلط الطوب الجديد. تم صب عينات من الطوب بالأبعاد 150مم×150مم×150مم بنسب مختلفة من مزيج من البولي ستايرين والجبس والجير والرمل. وأظهرت النتائج تباين مقاومة الانضغاط لنسب خليط مختلفة من المواد المذكورة. وقد تم تحديد قوة الانضغاط، والقدرة الاستيعابية، والعزل الحراري للطوب الذي تم إنتاجه حديثا مع

التركيب الأمثل بمختلف المطابع التي تصنع بالطوب. وأظهرت نتائج هذه الدراسة أنه كان من الممكن إنتاج طوب هيكلي جيد النوعية خفيف الوزن مقارنة مع الطوب الإسمنتي.

الكلمات الدالة: الطوب، قوة الإنضغاط، الجبس، الجير، بولي ستايرين.

1. Introduction

A lot of researches discussed that the brick masonry is the least understood in the aspect of strength and other performance related parameters because of its complex behavior. There are also restrictions on the excavation of top soil for the manufacture of clay bricks. On the other hand, sand-lime products (silicates) are environmentally friendly construction materials. Traditional silicates contain in their composition only sand, lime and water and their characteristic properties can be obtained. In recent years, much attention has been devoted to researches on modified sand-lime products containing among other waste materials, such as waste molding sands, post reclamation dusts, hematite tailings, fly ashes, bottom ashes, copper tailings, foam glass as well as recycled plastics. This study examines the effects of polystyrene and gypsum as reinforcements on the strength of sand-lime bricks. Lime, gypsum, and sand, with added waste polystyrene polymer constitute the major natural ingredients that were selected in this study. The overall purpose was to improve certain characteristics of silicates and at the same time, dispose of plastic waste. It is known from the literature that granulate of high impact polystyrene has very beneficial effect on compressive strength of silicates. The use of polystyrene waste in the production of new materials such as building bricks is a good step to get rid of them without damage, for example, when they are burned for disposal produces harmful gases.

2. Literature Review

Rahim, and Jamil (2014) studied on recycling of cigarette butts into fired clay bricks. Cigarette butts were mixed with the experimental soil and fired to produce bricks. The bricks became more porous and light as cigarette butts content increased. Light-weight bricks had great advantages in construction, lower structural dead load, easier handling, lower transport costs, and lower thermal conductivity. Light bricks can be substituted for standard bricks in most applications except when bricks of higher strength are needed or when a particular look or finish was desirable for architectural reasons. Liu *et al.* (2009) developed the brick made of pure fly ash and the manufacture of the brick did not involve high temperature heating in kiln, in contrast to manufacturing clay bricks. Consequently, using of greenest brick not only eliminated waste disposal of fly ash and saved landfill space, it also saved much energy and eliminated all the air pollution and global warming problems caused by burning fossil fuel in kilns to manufacture clay bricks. Long-term observation of the compacted fly ash bricks revealed that the long-term growth of strength of fly ash bricks was due to carbonation caused by absorption of CO_2 from the atmosphere which brings relief to global warming. Al-Wakeel *et al.* (1999) experimented the fly ash–sand–lime bricks and obtained the compressive strength, unit weight, water absorption and thermal conductivity under optimum test conditions. They suggested that it was possible to produce good quality of light weight bricks from the fly ash of Seyitomer power plant, Turkey. They concluded that the considerably low volume weight and low thermal conductivity of the fly ash bricks will reduce the construction and heating/cooling costs of the buildings. Kayali (2005) compared the properties of fly ash bricks to the clay bricks. The fly ash bricks produced were about 28% lighter than clay bricks. The mechanical properties of the fly ash bricks exceeded those of the standard load bearing clay bricks. Compressive strength was 24% better than good quality clay bricks. This reduction in the weight of bricks resulted in a great deal of savings in the raw materials and reduction in transportation costs. The resistance of the bricks to repeated cycles of salt exposure showed zero loss of mass and indicated excellent resistance to sulphate attack. Poon *et al.* (2002) found suitable alternative methods of brick manufacturing process to the existing materials. The properties of different proportions of fly ash at different baking temperatures were tested. Also they investigated their effects on compressive strength and water absorption quality of bricks by casting and testing. It was found that the bricks that were cast using 40% fly ash resulted in optimum strength. Blending fly ash in different proportions with the soil modified its consistency limits. However, the consistency limits did not have any noticeable effect on compressive strength of the bricks.

2.1. Brick Masonry

Mosalam *et al.* (2009) investigated the mechanical properties of masonry which was a heterogeneous composite in which brick units made from clay, compressed earth, stone or concrete were held together by mortar. Mortar of lime or a mixture of cement, lime, sand and water in various proportions were used. Consequently, masonry properties vary from one structure to the next depending on the type of brick units and mortar used. Rai and Goel (2007) used a simplified mechanics model to obtain the system capacity curve for an unreinforced masonry wall in which rocking piers were stabilized. Further, the system capacity curve for the entire wall was simply derived by assuming the pattern of story displacements after the first mode shape as it is the dominant mode for earthquake response in most structures. Ewing and Kowalsky (2004) captured the stress-strain characteristics of unconfined and confined clay brick masonry. Confinement plates dramatically improved the compressive strength of clay brick masonry. It was noted that confinement plates placed within the mortar bed joints restricted the lateral expansion of the joint and the differential expansion between the clay brick unit and the joint. Vintzileou and Toumbakari (2001) investigated the effect of deep rejointing on the behavior of brick masonry subjected to axial compression. In order to determine the initial compressive strength of masonry prisms, three of the specimens were tested in axial compression as constructed. In the remaining prisms deep rejointing was applied. In all specimens, typical vertical cracks due to compression appeared both along the length and the width of prisms. In addition to those cracks, spalling of bricks was observed in prisms to which deep rejointing was applied. The spalling of bricks was attributed to the concentration of stresses in the region of the new mortar having substantially higher strength and modulus of elasticity than the old one. Deep rejointing leads to substantial increase of the compressive strength of masonry, provided that horizontal joints were completely filled.

2.2. Compressive Strength of Fly Ash Brick with Addition of Lime, Gypsum and Quarry Dust

The experimental investigation was carried out to find the optimum mix percentage of fly ash brick by Banu *et al.,* (2013). Compressive strength was studied for different mix proportions. The results shows the variation of compressive strength for different mix proportions of materials mentioned earlier at different curing ages..

2.3. Polymer Reinforced Laterite for Building Materials

Osula (1989), evaluated admixture stabilization for problem laterite and focused on the potential in locally available materials to produce alternative building materials at low cost. Laterite was reinforced with plastic particulates obtained from plastic wastes (as matrix), recycled pure water sachet and vulcanized rubber (as reinforcement). The compression test and flexural test were carried out using a tiratest-2810 universal electromechanical testing machine, the results of the experiments, polymer reinforced laterite composite is a potential alternative to conventional building materials. This is evident from the improved mechanical properties especially the compressive strength.

2.4. Performance of Sand-Lime Products Made with Plastic Waste

Nowek (2016), performed experiments on sand-lime (silicate) masonry units modified with recycled plastics in various forms: regranulate, regrind and powder. The purpose was to investigate the improvement in the mechanical characteristics of silicates and at the same time, dispose of plastic waste. Grain size distribution of sand influences the mechanical properties of silicate materials and the process of lime slaking in silicate mass takes place. The author introduced to the sand lime mass 15% of polymer (per weight). The specimens were tested and good results were concluded.

3. Material and Experimental works

3.1. The Used Materials

3.1.1. Silica Sand

Silica materials are located in various regions of Libya in large quantities and different mining conditions, and the silica sand used in this study was from south Ajdabiya. The percentage of silicon (SiO_2) reached 99.5%, making these materials very suitable in the manufacture of all types of glass, crystal and semi-crystalline high-quality without needs of any important

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treatment, as well as in the manufacture of cement, building materials and as a filler in paint and brick making and sand and concrete elements can also be used in electronic industries.

3.1.2. Polystyrene (Wastes of Electronica Packing 'EPS')

Polystyrene is a thermoplastic material shown in Figure (1) obtained by the polymerization of styrene and is used in packaging electronics, food items and building houses is one of the most common forms of packaging and cushioning material used today when expanded in foam form, EPS is approximately 96% air.

Figure 1. Polystyrene wastes

3.1.3. Lime

"Lime" refers to both limestone ($CaCO_3$) and its derivatives burnt lime (CaO) and hydrated lime ($Ca(OH)_2$). Burnt lime is produced from limestone by heating to 1100 ^oC and allowing the following reaction to take place:

$$CaCO_3 + heat \rightarrow CaO + CO_2 \uparrow \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Hydrated lime is produced by adding water to calcium oxide in a continuous hydrator:

$$CaO + H_2O \rightarrow Ca(OH)_2 + heat \uparrow \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

Hydrated lime is type lime used in our study.

3.1.4. Portland Cement

Cement is a hydraulic material composed primary of calcium silicates, aluminates, and ferrites. In a rotary kiln, at temperature reaching the 1450 ^oC, clinker nodules are produced from a finely ground, homogenized blend of limestone, shale and iron ore. The nodules are subsequently ground with gypsum, which serves to control setting, to a fine powder to produce finished Portland cement. The composition and texture of clinker phases result from complex interactions of raw feed chemical and mineralogical composition, particle size distribution, feed homogenization,

3.1.5. Libyan Gypsum

Libyan gypsum was used in this paper. Gypsum resources in Libya were estimated to be 8.4 *M Tones* with thicknesses of up to 350 *m*, and estimated that the Jefren deposit contains one of the world's highest concentrations of pure gypsum (up to 99.5% calcium) (Taib, 2011).

3.1.6. Aggregate (Gravel)

The gravel used is very small and very hard it has sharp corners with the addition of lighter weight of the other types of gravel it was obtained from stone crushing factories west of Ajdabia city.

3.2. Method of Application

At the beginning, experimental samples free cement and gravel were used to discover the extent of success, by these stones, in resisting high compacting force without cement, while making cement blocks for comparison.

- Four mixing ratios were used in these experimental samples.
  - These ratios were not random; two of them were obtained from a study, and two were gained after research and comparisons for the properties of these items with respect to the required property which is mainly the resistance against breaking and high compacting.
  - These ratios were applied with constant, but relatively light pressure.
  - Then, and after testing their resistance for breaking, the best ratio was chosen, in comparison with the result of testing the resistance for breaking of the local sample and working on it. Also by obtaining numerous good ratios obtained from it by using "up-down" method for the ratio of each element in the compound.
- Four ratios fairly close to the good ratio were attainable.
  - Gravel and cement were added with constant ratios for each of them; where gravel was 5% with respect to polystyrene and the cement was 3% for gypsum.
  - Stress was increased by increasing gravel, there by scarifying, somewhat, the light weight provided by polystyrene.
  - An increase in cohesion and solidarity was gained by increasing cement; a property that gypsum shares modestly with the cement.
  - These ratios were applied under different pressures for each one.

There was a sample without cement for ratio and two samples; one with light pressure and the other with high pressure. The total number of samples was twelve.

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Then the breakage resistance of these samples were chosen and compared with the resistance of the local cement blocks where the results were very high for 3 samples only and the rest were between average and good.

The three good samples were chosen for removing cement from them and applying them without cement; in order to return to the origin of the study which is "Producing building stones with good properties that are environment friendly".

3.3. Method of Mixing

Preparation of the samples consists of:

1) Obtaining all materials, except gravel, in powder form.
2) Mixing these materials according to their ratios.
3) Making into paste by spraying water.
4) Molding in concrete testing molds of size, 15 *cm*×15 *cm*×15 *cm*.
5) Compacting then putting molds on the vibrator.
6) Finally, applying pressure and putting molds in a leveled place.

Getting the sand, lime and gypsum soft such as powder then screened, but the polystyrene is scattered, there after all materials are well mixed in certain rate for every material, then puddle with water in room temperature, and prepare the samples in molds of volume 0.15×0.15×0.15 m^3 (as shown in Figure 2).

Figure 2. Preparation of samples in testing molds size: 15 *cm*×15 *cm*×15 *cm*

3.4. Mixing Ratio

- Preliminary sampling rates
- Secondary sampling rates with 5% aggregate and 3% Portland cement for each sample
- Recent sample rates without cement but with 5% aggregate

3.5. The Pressure

A special device was designed for pressing these samples, the scale can weigh up to 150 *kg*; and two vehicle jacks with steel frame was used; the jacks are connected with iron rod with press at its end to press the samples.

Figure 3. Pressure device for pressing samples

3.6. Method of Testing

Weighing the sample before the 7 *days* for the three cases; then weighing it after 7 *days* and calculating the difference between them. This result is then compared with a local sample (Cement block).

3.6.1. Pressure Stress Test

Stress is an important property for building materials, such as concrete and blocks; since as stress increases for these materials, so dose its quality; thereby increasing the building capacity for endurance. As such we adopted this test as a min paring for samples success. This was concluded after comparing the samples results with the standard specifications of the American society for testing and material that register 3.5 *N/mm²* as a minimum value for block success. Samples were tested using the device after 7 *days* of making dough and pouring in molds to guarantee complete solidification of sample (as shown in Figure 4).

Figure 4. Break test

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3.6.2. Water Absorption Test

This is the degree of water absorption by bricks. The increase in water absorption has negative effect on quality since it increases humidity in painting and plastering. Then, this test is applied only to samples of good stress, in three situations. First one when the block is in the open air 7 *days*; second one when the block is in a humid atmosphere (placed in a wet cloth) and the third situation when it is submerged in water for 7 *days* (as shown in Figure 5). Equation (3) was used to calculate percent of water absorption.

$$W_3 = \frac{W_2 - W_1}{W_1} \times 100 \qquad \text{.............................. (3)}$$

where: W_1= weight of dry brick in *kg*, W_2=weight of brick after immersion in water, W_3=percent water absorption.

Figure 5. Water absorption test

3.6.3. Thermal Insulation Test

Heat insulation is a reduce of heat leakage from outside to inside the building in summer, and from inside to outside the building in the winter, in this work the thermal insulation was measured by a different method, in which we have made a cavity for a special sample for this test and a traditional sample for comparison between them, pour hot water with known heat in this cavity and closed by insulator, after an hour, we measure water temperature inside the cavity and compare the water temperature before and after pouring by one hour (Figure 6), this method was proposed to measure thermal insulation because it is important, where no device was available in our city.

Figure 6. Special sample for thermal insolation test

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4. Results and Discussion

Several tests were carried out and conducted to find the optimum mix percentage of new bricks in the laboratory. Performance of bricks is measured on the strength; however the brick specimen of size 150 *mm*×150 *mm*×150 *mm* were cast for different mix percentage of sand, lime, gypsum and polystyrene. The specimens have been tested for several mix proportions; the specimen which had maximum optimized compressive strength is obtained for optimal mix percentage. Based on the experimental study carried out, the rest of tests on the specimens such as absorption capacity of water and thermal insulation are compared with cement bricks. Mix proportions are arrived by referring the articles and data collected from local manufacturing companies. For the various proportions arrived bricks are casted and the following tests were conducted.

4.1. Compressive Strength

To estimate the strength of bricks, cubes of size 150 *mm*×150 *mm*×150 *mm* were casted for carrying out compressive strength test. The specimens were tested on a compression testing machine with capacity of 2000 *kN*. All the specimens had same forming pressure which was 26.1 *kPa*. From the experimental results proportion in Figure (7.a) shows the maximum compressive strength value was 4.28 *MPa*. The compressive strength decreases with increases of polystyrene content and lime. Figure (7.b) shows the compressive strength of new bricks. While it can be seen that the compressive strength increased from 2.07 *MPa* for increased 3 percent gypsum to 4.28 *MPa* for an optimum gypsum content of 25%. However, the maximum load is 96.3 *kN* of sample X1 as shown in Figure (7.a).

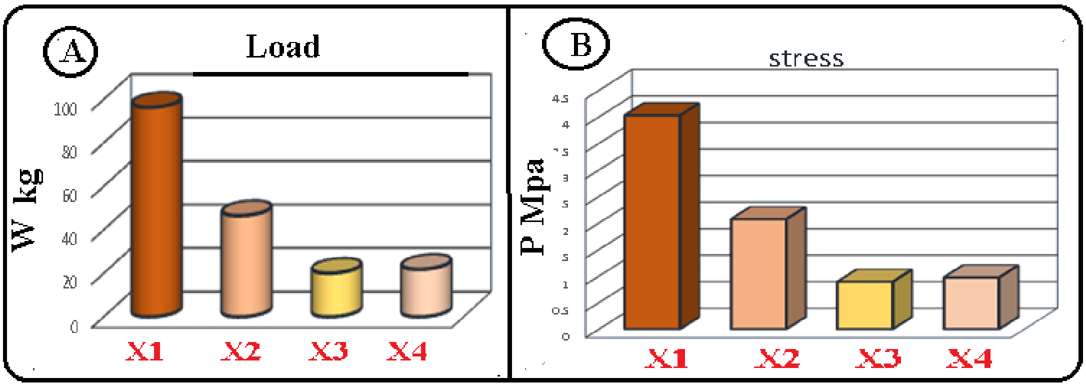

Figure 7. Results of weight load and stresses of different samples

Nomenclature:

X1- Sample contents of 20% sand, 10% lime, 45 % Polystyrene and 25% Gypsum
X2- Sample contents of 23% sand, 14% lime, 41 % Polystyrene and 22% Gypsum
X3- Sample contents of 15% sand, 20% lime, 55 % Polystyrene and 10% Gypsum
X4- Sample contents of 18% sand, 17% lime, 50 % Polystyrene and 15% Gypsum

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4.2. Arriving Proportions

Mix proportions are arrived by choosing the samples which have the high compressive strength without forming pressure and adding 5% aggregates. Form that we noted the Compressive strength was decreasing in all samples, so adding cement and aggregates could have negatively effect on the compressive strength of new brick. Furthermore; that proportion of sample X1 was taken as an optimal mix percentage of new brick (polystyrene 45%, Lime 10%, Gypsum 25%, and sand 20%). However the experimental result of X1 was accepted because it pass the minimum required stress for building block according to the American Society for testing which is 3 *MPa*.

4.3. Results of New Bricks Compared with Local Cement Bricks

Based on the experimental study the optimal mix percentage of New bricks is (polystyrene 45%, Lime 10%, Gypsum 25%, and sand 20%) without forming pressure, where casting several samples of X1 which called New bricks sample. On other hand in this comparison cast local bricks (cement where the mix design had been taken from Ajdabiya city market). However the specimens have been subjected to several tests to achieve the objectives of the study, the following tests were conducted compressive strength, water absorption, and thermal insulation for the 5 samples of each kind of bricks:

4.3.1. Comparison of compressive strength results

Table (1) and Figure (8) show that the compressive strength of new brick is 32% greater than the normal cement brick could be due to good adhesive happen between gypsum and sand. However, the minimum compressive strength of cement brick is 3.02 *MPa*. So as the new brick has compressive strength of 4.5 *MPa*. Bricks to be used for different works should not have compressive strength less than as mentioned above. The universal testing machine is used for testing the compressive strength of bricks. While, max load of new bricks is 50 % greater than local sample, Figure (8) shows the max load of each sample, and weight of new bricks is 17% less than local one.

Table 1. The results obtained from lab test between N.B and L.B

Data / Type	Max Stress (*MPa*)	Max Load (*kN*)	Weight (*kg*)
New brick sample (N.B,)	4.25	101.25	5.6
Local brick sample (L.B.)	3.02	67.95	6.3

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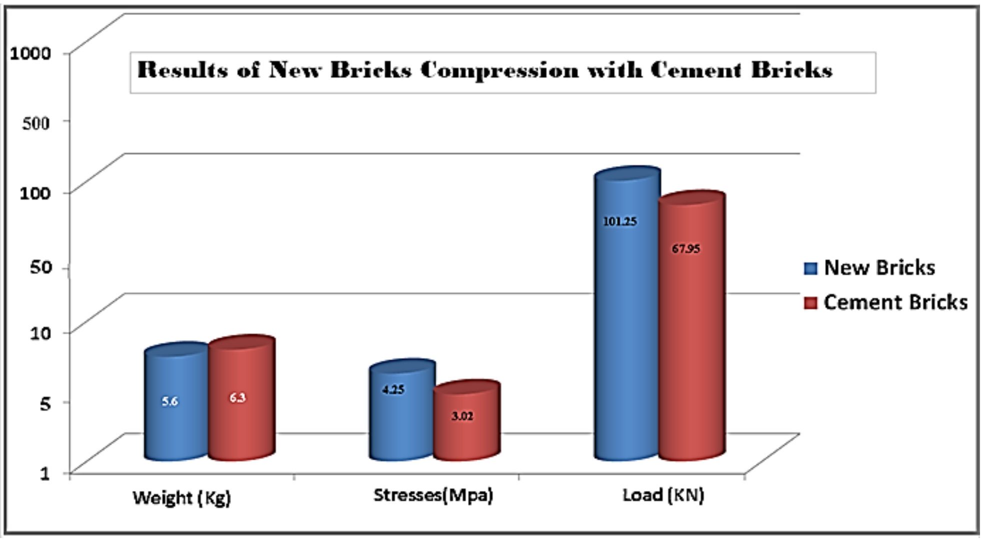

Figure 8. The results of New Bricks and Cement Bricks by weight, stress and load

4.3.2. Comparison of water absorption

To estimate water absorption 6 specimens had been casted 3 for new bricks and other one for local bricks to compare between them. When they completely dried and weighed (W_1) brick in different curing process and time effects of three different curing processes i.e. in still air, keeping the specimen under wet cloth and keeping the specimen immersed under water for three weeks and four days were examined. After that remove, the bricks and wipe out any traces of water and weigh immediately (W_2).

$$\text{Water absorption } (\%, wt.) = \frac{W_2 - W_1}{W_1} \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

Generally Table (2) shows water absorption property.

Table 2. Water absorption property

	W_1 (*kg*)	W_2 (*kg*)	The difference	W_1 (*kg*)	W_2 (*kg*)	The difference
In air	5.3	6	13.21%	6.6	7	4
Under water	5.4	6.3	9 g	6.3	6.8	5
Under wet cloth	5.6	6.4	8 g	6.4	6.9	5

4.3.3. Comparison of thermal insulation

This test could be a traditional way to know thermal insulation, two specimens of new brick and local brick had casted and made cavity like cylinder in the mid of them by depth 7 *cm*. after that pour hot water known heat 45.5 ^oC in this cavity and closed by insulator, after an hour, we measure water temperature inside the cavity and compare the water temperature before and after pouring by one hour as shown in Table (3).

Table 3 Resultes of thermal insulation for N.B and L.B

Type \ Data	Temperatures		Difference
	T_1 (°C)	T_2 (°C)	
New bricks (N.B)	45.5	37.2	8.3
Local bricks (L.B)	45.5	30	15.5

5. Conclusion

From the experimental work performed in this study, the following can be concluded:

- It was possible to produce better quality building material by using the method of compound materials.
- Using natural elements found in abundance like (sand, limestone and gypsum) which can reduce the cost of producing the element.
- Using polystyrene waste, as additive, is good for reducing weight and contributing to cleaning the environment.
- The combination of "limestone, gypsum, sand and polystyrene" produced the best mix for stress, that which contain gypsum over 15 % of volume.
- After testing a number of mixes, with various ratios of polystyrene, it was found that it did not affect stress but contributed to the reduction of weight to a great degree.
- Pressure affects stress negatively, thus when we increase pressure, the sample stress is reduced gradually.

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