# THE STRENGTH, DEFORMATION AND THERMOMECHANIC PROPERTIES OF CRUSHED BRICK AGGREGATE LIGHT-WEIGHT CONCRETE

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Received March 30, 1989
Presented by Prof. Dr. Gy. Balázs

## Abstract

Appropriate mixtures of brick LWC for wall and ceiling elements were developed for the Hungarian Brick and Tile Trust.

Dur main conclusions are the following:

The production of wall and ceiling elements is possible from only brick aggregate LWC.

The designed LWC mixtures resulted in C4—C12 (B70—B200) concretes and their body density was between 1700—1800 kg/m$^3$.

The thermomechanic properties of brick LWC and brick are comparable and the brick LWC is 10—12% better as a heat insulator than is a brick wall.

The hardening of brick LWC is faster because of the water absorption of brick aggregate and the elements are transportable one day after casting.

The prototype ceiling elements from brick LWC satisfield the relevant Hungarian Standard (MSZ 10798/2). The brick LWC elements are lighter, better heat insulators, have better adhesion with mortar, harden faster and their production is technically developed and economical in comparison to traditional elements.

## 1. Introduction

Crushed brick was already used as a raw material for concrete in the age of the Romans. According to Reinsdorf [10] they were using pieces of bricks as concrete aggregate. In 1850 in Germany concrete pipes were already made with crushed bricks. After World War II in Germany a detailed technology of producing crushed brick aggregate light weight concrete was developed to clear up war debris and ruins. In 1952 the first standard for designing crushed brick LWC was worked out by Charisins, Drechsel and Hummel [2].

In Hungary the substandard products of brick factories are used instead of war debris or remains of demolished buildings. The application of crushed brick LWC is in the interest of either the brick factories to use up their large quantity of waste or the builders, especially in areas where mixed river aggregate is not available.

With the direction of a Hungarian Government Management Plan (Recirculating Industrial Waste and Economic Material Consumption) and the financial fund of the Hungarian Brick and Tile Trust an appropriate technology for producing wall and ceiling elements from crushed brick LWC was developed by the Building Materials Department of the Technical University of Budapest.

The adaption of experiments and results on crushed brick LWC from other countries was not possible because of the different physical and mechanical properties of each type of brick or tile used for LWC.

## 2. Testing of raw materials (crushed brick, cement, sand), summarized results of tests

The crushed bricks from the factories in Solymár and Kisujszállás were tested. Both factories belong to the Hungarian Brick and Tile Trust. The physical properties of crushed brick and the effects of the quantity and quality of cement on the physical, strength and thermomechanic properties of LWC were examined. Special attention was paid to the extra water requirements of dry and porous brick particles and to the strengthening procedure at the age of 90 days.

The physical properties of *crushed brick* from Kisujszállás (8):

| | | |
|---|---|---|
| maximum diameter | $d_{\max}$ | = 8 mm |
| fineness modulus | $m$ | = 5.13 |
| fine parts (0/1) | 32% (by mass) | |
| density | $\varrho$ | = 2.603 g/ml |
| body density | $\varrho_b$ | = 1.730 g/ml |
| bulk density | $\varrho_h$ | = 1.023 g/ml |
| water saturation (1 hour) | $w_f$ | = 34.3% (by mass) |
| total porosity | $n_{\ddot{o}}$ | = 0.60 |
| bulk porosity | $n_h$ | = 0.19 |
| gap ratio | $n_{h,h}$ | = 0.41 (41%) |

Figure 1 shows the grading of the crushed brick which was used during laboratory tests. The *cement* was: Vac 350 kspc — 20, MSZ 4702 ($\varrho = 3.115$ g/ml). In the case of LWC every strength-body density resulted in different optimum grading [7]. The effects of grading, quality and strength of raw materials on the final strength of LWC are summarized below.

The portion of fine particles (0/1 mm) has the greatest effect on the strength of LWC, and the effects of coarser aggregates on body density and strength are less important.

If the fine portion of crushed brick is replaced by quartz sand the strength increment is significant, the body density increases but the thermomechanic properties are worse.

The greater the strength of crushed brick particles, the greater is the strength of LWC made with it.

When *river sand* is added to crushed brick aggregate LWC its strength and its body density increase. Our tests show that added sand should be limited to around 20% by mass for an optimum. Some sources in the literature [5], [6] indicate that this value is between 15—25%. Replacement of 10—40% of fraction 0/4 by river sand increases body density by 20—30% and increase cube strength by 50—70%.

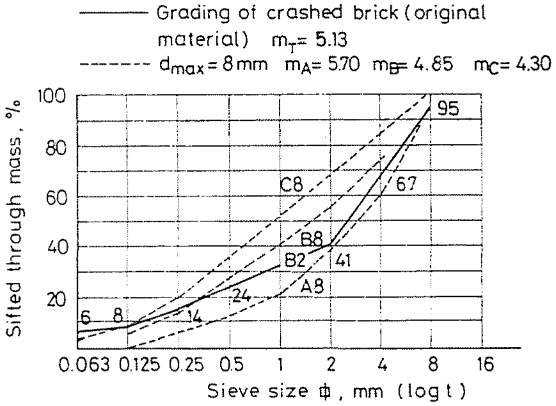

*Fig. 1.* Grading of the crushed brick

The effect of added *polystyrene foam* on the thermal conductivity was also examined. The body density of the LWC decreases and the thermomechanic properties are better. The highest strength was achieved when about 20% (by volume) polystyrene was used in the concrete. More polystyrene aggregate produced very low compressive and flexural strength.

Polystyrene added LWC-s are suited to manufacture wall elements with compressive strength between 60—140 MPa depending on the components of concrete.

Previous tests according to [8] have proved that the method of placing LWC has only a minor effect on body density and 15 sec vibration resulted in the highest measured cube strength.

## 3. Concrete components

Hungarian and foreign research has already produced tests to determine the components of such LWC. [2], [3], [9], [10], [14], [16], [17], [18]. The effect of the water-cement ratio on th strength is not as clear as in the case of river aggregate concrete. However, the water-cement-air ratio has a clear correlation with the strength [16], [18]. In the knowledge of these vital properties of LWC, during the tests of Palotás [7], equations were used to determine the components of concretes. The crushed brick absorbs water fast and about 70—80% of water absorption takes around 30 minutes. Thus for designing LWC using crushed brick the 1 hour water absorption test is very important. The porosity of brick largely influences the amount of water necessary for LWC and determines the proper amount of mixing water necessary.

It is suggested to use the following equation based on our test results:

$$V_T = 0.76\,(0.2C + w_f \cdot \mathrm{A}), \text{ where} \qquad (1)$$

$V_T$ = the total amount of water, l/m$^3$
$C$ = cement content, kg/m$^3$
$A$ = aggregate content, kg/m$^3$
$W_f$ = water absorption (1 hour)
0.76 = factor from experiments.

The components for the LWC mixture were measured according to the following sequence:

— weighing and dry mixing of crushed brick,
— wet mixing of brick with 60% of the total amount of water needed,
— weighing cement and mixing it with the wet brick,
— adding the rest of the water needed to set final consistency (fully mixed three times).

For compressive tests $200 \times 200 \times 200$ mm$^3$ specimens were made. $70 \times 70 \times 250$ mm$^3$ specimens were also made to carry out flexural and body strength tests.

### 3.1 *Determination of strength properties*

Table 1 shows the suggested LWC mixture (without added sand) using crushed brick and Table 2 gives the strength properties. The effects of quantity and quality of cement are:

— increased quantity of cement in the LWC increases strength but also increases standard deviation (11). 20% more cement increases strength by 10% [7], [9],

— using cement with a higher strength the strength of LWC increases but the increment of strength is not a linear function of the cement quality as was experienced with normal concretes.

Figures 2, 3 and 4 give the effects of changing the cement content. The strengthening procedure of such types of LWC is also very unique. The hardening rate of LWC, particularly in young concrete, is marginally different from the hardening rate of normal concretes.

**Table 1**

| Specimen No. | Sign. | Concrete composition kg/m³ | | | Density kg/m³ | | Cube strength MPa (mean) |
|---|---|---|---|---|---|---|---|
| | | cement | pulverized brick 0/8 | water | at making | after 28 days | |
| 1 | T1 | 350 | 1063 | 330 | 1960 | 1770 | 24.7 |
| 2 | T5 | 275 | 1140 | 359 | 1823 | 1725 | 14.8 |
| 3 | T8 | 225 | 1188 | 370 | 1805 | 1710 | 10.0 |
| 4 | T7 | 200 | 1213 | 405 | 1875 | 1790 | 7.6 |

**Table 2**

| The concrete | cement content kg/m³ | Characteristic strength after 28 days, MPa | | | Classification of concrete | |
|---|---|---|---|---|---|---|
| | | cube strength | bending pulling strength | strength (body) | old | new |
| T1 | 350 | 24.7 | 4.64 | 25.5 | B 200 | C12 |
| T5 | 275 | 14.8 | 3.59 | 15.0 | B 140 | C8 |
| T8 | 225 | 10.0 | 2.11 | 10.6 | B 100 | C 6 |
| T7 | 200 | 7.6 | 1.61 | 7.1 | B 70 | C 4 |

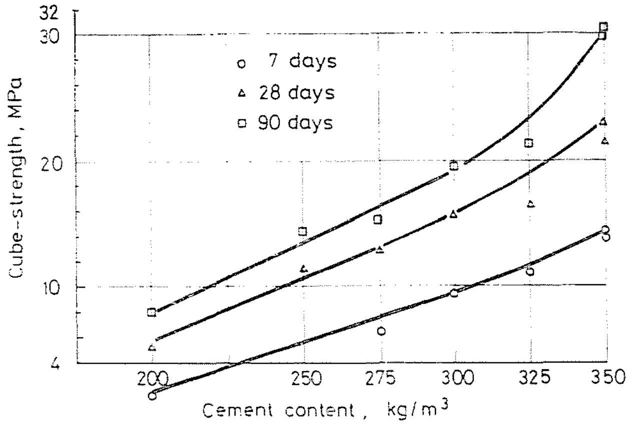

*Fig. 2.* Cube strength of different age concrete versus cement content

During laboratory tests air dry bricks were used and it was found that the sudden water absorption of brick increases the early strength of LWC dramatically.

The water absorption is initially very fast (the 80—90% of total absorption takes place in the first hour) and this results in quick hardening [8], [14]. The one hour water absorption of brick resulted in an average $w_f = 34.30\%$ (by mass) during our tests.

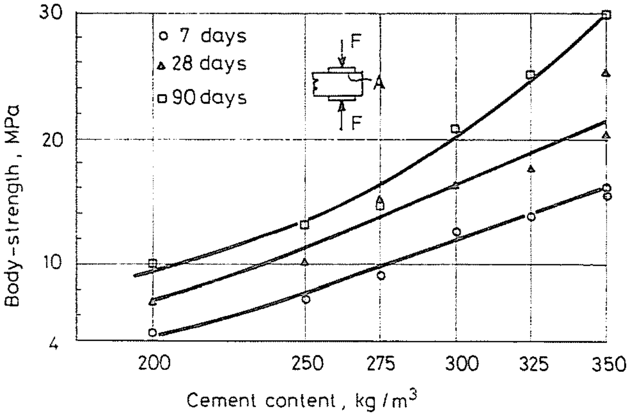

*Fig. 3.* Body strength of different age concrete versus cement content

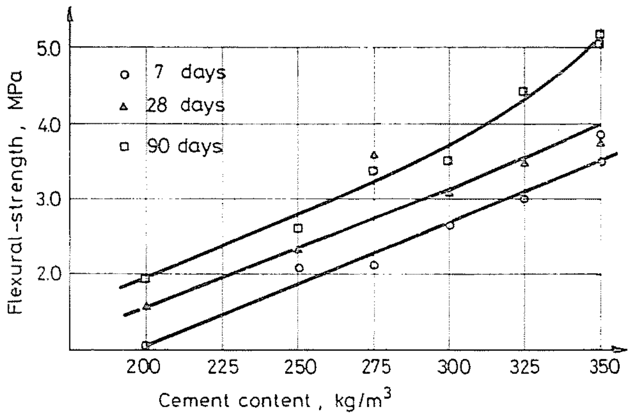

*Fig. 4.* Flexural strength of different age concrete versus cement content

The hardening rate of young concrete was tested and the T1 specimen was used. The hardening rate is given in Figure 5. All specimens were removed from form work after 5 hours. 8 hours after casting the specimens were transportable. A significant post-hardening (hardening after 28 days) was also observed during tests. The 90 days old T1 specimen exhibited a 30.6% increase in cube strength, the T7 specimen a 30% increase in strength in comparison to the strength values which were measured 28 days after casting. The flexure strength increased by 10—44% and the compressive body strength increased by 40—45% during this 62 day period.

Figures 6, 7 and 8 show the hardening vs. time relationship.

The cube strength ($R_c$) factored by 1.05 gives a reasonably accurate value for the body strength at the age of 28 days. The flexure strength is estimated as 21% of the cube strength (28 days old LWC).

The body density of every LWC mixture was tested. The resulting relationship between the body density and the age of concrete is shown in Figure 9. The relationship between the dry and wet (fresh) body density was obtained as

$$\varrho_{td} = b\, \varrho_{tb}, \text{ where} \tag{2}$$

$\varrho_{td}$ is the dry body density of LWC (kg/m$^3$)
$\varrho_{tb}$ is the fresh body density of LWC (kg/m$^3$) and
$b$ is the factor from tests between 0.80—0.85.

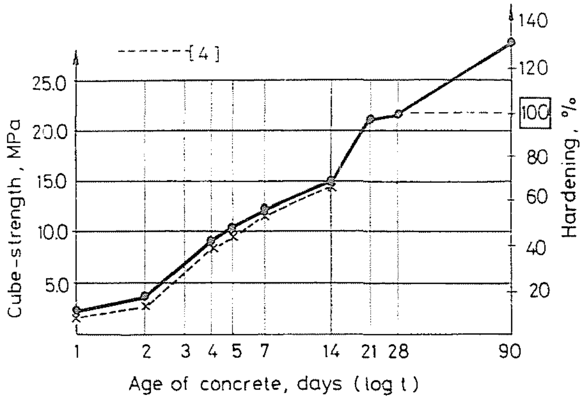

*Fig. 5.* Hardening rate of young LWC

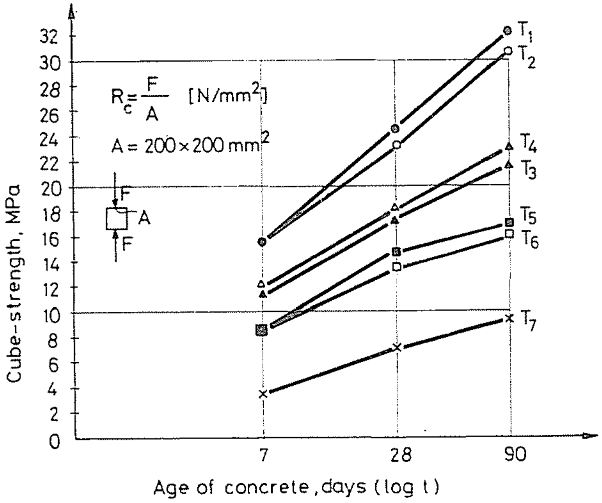

*Fig. 6.* Cube strength versus age of LWC

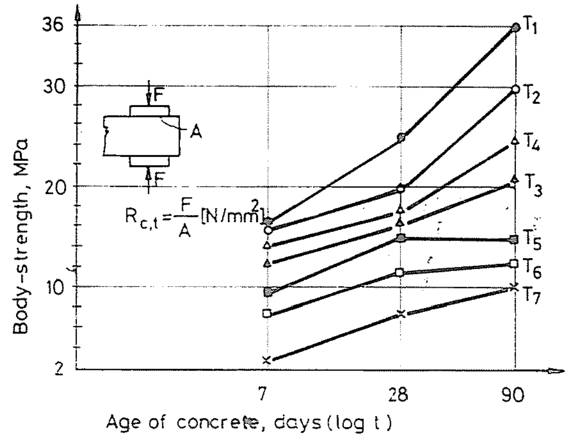

*Fig. 7.* Body strength versus age og LWC

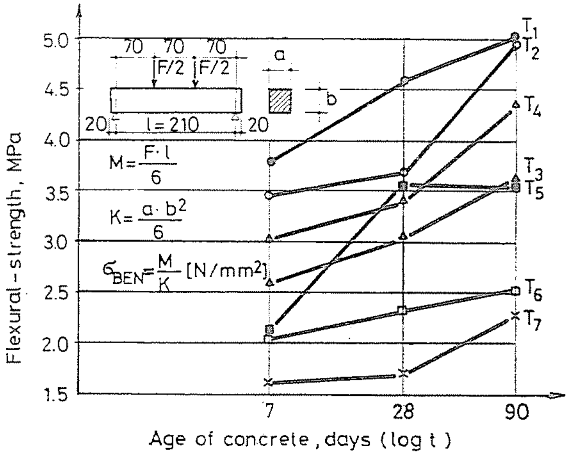

*Fig. 8.* Flexural strength versus age of LWC

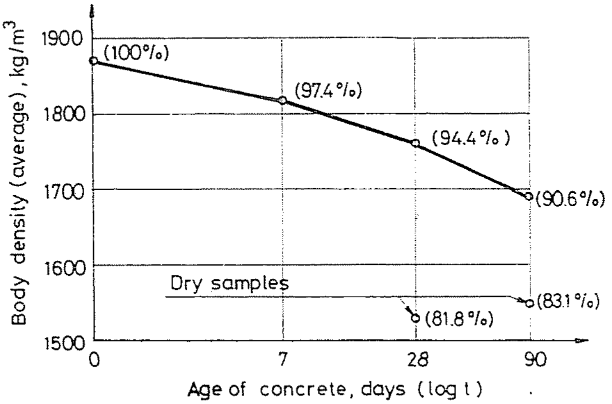

*Fig. 9.* Body density versus age of LWC

### 3.2 *Determination of deformation*

The shringage of LWC (light, porous material stores the water) is slower than that of normal concretes. The initial water absorption keeps cement paste wet for longer periods. According to Palotás [7] the total shrinkage of dry LWC in dry air is about 0.4—1.0%. Our tests indicated shrinkage between 0.48—0.61% (average was 0.54%) when LWC was 90 days old.

To find the short term deformation properties the full $\sigma$-$\varepsilon$ diagram was drawn from the unloaded stage to the ultimate load. The initial Young-modulus ($E_0$) of the tested LWC-s varied between 10400—17600 MPa (10.4—17.6 kN/mm²). The Young-modulus of LWC-s also depended on their dry body density.
The initial Young-modulus is given as

$$E_0 = \beta \cdot \sqrt{\varrho_d^3 \cdot R_{c\Box}}, \quad \text{where} \tag{3}$$

$\varrho_d$ is the dry body density (kg/l)
$R_{c\Box}$ is the cube strength (28 days, MPa) and
$\beta$ is the factor (determined by the aggregate).

A $\beta = 2200$ is suggested for crushed brick LWC according to our test work (Table 3).

**Table 3**

| Origin | Sign. of specimen | Dry density kg/m³ | Characteristic strength MPa | | Initial modulus elasticity $E_0$, MPa | Factor | |
|---|---|---|---|---|---|---|---|
| | | | Prism strength $R_{c,pr}$ | Cube strength $R_{c\Box}$ | | single | mean |
| Budapest | T6 | 1530 | 5.35 | 7.10 | 12800 | 2538 | |
| Bécsi-street | T4 | 1600 | 8.44 | 10.70 | 15200 | 2296 | 2280 |
| brick-works | T5 | 1670 | 10.69 | 13.80 | 16400 | 2007 | |
| Kisújszállási | T1 | 1544 | 18.30 | 21.20 | 17600 | 1993 | |
| brick-works | T5 | 1558 | 16.10 | 14.80 | 17360 | 2320 | 21219 |
| | T7 | 1490 | 6.94 | 7.60 | 10400 | 2075 | |

### 3.3 *Thermal conductivity of brick LWC*

Brick LWC has 10—12% better thermomechanic properties than brick walls thus it is regarded as the same as if it were brick. The thermal conductivity ($\lambda$) was measured with a Bock-device at 25 °C and the results obtained were between 0.46—0.54 W/m°K.

## 4. The design and tests of the prototype of a brick LWC ceiling element

After testing the physical and mechanical properties of brick LWC a mixture of brick concrete was designed which had the appropriate body density, strength and thermomechanic properties for a ceiling element. The first series of ceiling elements were made in the brick factories in Solymár and Kisujszállás using a hydraulic press (type HBSF 1200/3). The ready prototype elements were tested according to the relevant Hungarian Standard (MSZ 10798/2).

The brick LWC prototype ceiling elements were better than the similar ones made from quartz aggregates because:

— their average body density was 1750 kg/m$^3$ and thus they were lighter,

— the flexural strength satisfied the relevant Hungarian Standard (MSZ 10798),

— the hardening of young concrete was faster because of the water absorption of brick thus the 24 hour old LWC elements were already transportable,

— the brick LWC worked well with the gap filling concrete between beams,

— the post hardening after 28 days was significant (30%),

— thir thermal conductivity was lower than in the traditional concrete elements,

— the mortar sticks well onto their surface and the lack of "heatbridge" means no colouring on the mortar surface.

It was suggested to plant the facilities producing the LWC ceiling elements close to brick factories and to use the existing machinery and some technical-technological guidelines were set up by the Building Materials Department [5].

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