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Properties of Lightweight Concrete Blocks with Waste Zeolitic Tuff

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In general, three different types of wall products commonly used in the building sector, namely traditional clay brick, lightweight concrete blocks and aerated concrete, contain pumice and perlite. We have created alternative block walls with Bayburt stone (BS) containing zeolite, namely lightweight concrete masonry blocks (LCMBs). BS was an aggregate, cement dosages ranging from 150 to 250 kg/m^3 were a binder, 3 different type of superplasticizers were selected as a chemical additive. Compressive strength, water absorption, unit weight, elevated heat effect, freeze-thaw resistance, capillary water absorption and thermal conductivity tests were performed. Compressive strength and freeze-thaw resistance of LCMBs are higher than the respective values for the other traditional wall products - with less amount of cement usage. Compressive strength values of lightweight concretes (LCs) were between 4 MPa and 9 MPa on the 3rd day, unit weights of the LCs were between 1.43 and 1.60 kg/dm^3, thermal conductivity values of the so produced block wall elements were ≈ 0.55 W/mK.

Keywords: lightweight concrete, block wall elements, thermal conductivity, compressive strength, elevated temperature concrete.

1. INTRODUCTION

The use of lightweight construction materials is very important – especially in earthquake zones. Usage of lightweight materials as partition wall elements is highly preferred in buildings. Unit weights of concretes produced with lightweight aggregates range from 800 to 2000 kg/m^3 [1]. Natural aggregates such as tuff and pumice are volcanic based and their densities varies between 0.65 and 1.85 g/cm^3 due to high porosity [2]. Currently 3 types of elements are used in building partition walls: traditional hollowed clay bricks, aerated concrete and hollowed cement based blocks produced with perlite or pumice. Each of these materials fulfills standards – with different geometrical shapes and predefined properties which differ from country to country. For instance, in Turkey the hollowed clay bricks need a maximum 1.6 kg/dm^3 of unit weight and compressive strength up to 8 MPa; cement based hollowed blocks have to have unit weight below 1.6 kg/dm^3 and minimum 2 MPa compressive strength with roughly 400 kg/m^3 dosage; aerated concrete blocks have unit weight below 0.6 kg/dm^3 and minimum 5 MPa compressive strength with 400 – 550 kg/m^3 dosage cement. Also in Turkey thermal conductivity of all the masonry elements has to be maximally 0.75 W/mK. Needless to say, there have been around the world various studies aimed at decreasing unit weight and moisture permeability, increasing strength, enhancing radiation shielding capacity and freezing and thawing durability [3 – 11].

Production of currently used wall elements requires much energy – resulting in extensive CO_2 emission and high costs. Turkey has abundance of different types of natural minerals such as hematite, limestone, marble, travertine, onyx, pumice and tuff which was created in volcanic eruptions. In the Bayburt region of Turkey, tuff is called Bayburt Stone (BS). This region has a rich reserve of tuff that is used as capstone with/without being sculpted. During quarry and cutting process, 70 % of the tuff turns into waste. A part of such waste consists of particles called Palladian and also fine particles in the form of sawdust. Needless to say, waste dust is an environmental pollutant.

Recently, irrespective of political, economic or ecological reasons, recycling has been encouraged throughout the world since waste and waste disposal have become a severe social and environmental problem - and that includes making concretes. We need to reduce the impact that the environment can suffer from the consumption of raw materials and the almost random generation of waste [12 – 17]. Recycling has the potential to reduce the amount of wastes disposed of in landfills and to preserve natural resources. Recycling, one of the strategies in minimizing waste, offers three benefits: (i) reduces the demand for new resources; (ii) cuts down on transport and production energy costs; (iii) utilizes waste which would

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otherwise go into landfill sites. Concrete containing wastes can support construction sustainability and contribute to the development of the civil engineering area by using industrial waste, lowering the consumption of natural resources and producing more efficient materials.

The purpose of our work was determination of feasibility of using waste tuff in fabrication of lightweight concrete blocks - what involved determination of the effects of waste tuff on properties of lightweight concrete block wall elements.

2. MATERIALS AND METHODS

Ordinary Portland cement (OPC) we used as a binder was CEM I 42.5R (OPC) from Askale Cement Factory in Erzurum. Physical and mechanical properties of the OPC are presented in Table 1 and chemical properties in Table 2. The cement content in the mixtures was in a range from 150 to 250 kg/m^3. BS was used as the aggregate.

Table 2. Chemical analysis of OPC and BS (weight %).

Compound	OPC	BS
SiO_2	18.1	68.9
Al_2O_3	4.6	11.9
Fe_2O_3	2.9	0.34
CaO	64.5	3.85
MgO	2.34	1.29
SO_3	2.95	0.21
Na_2O	0.13	0.23
K_2O	0.66	2.38
LOI *	3.31	10.1
* Loss on ignition		

Three kinds of chemical admixtures were used as plasticizers. The first one was naphthalene sulfonate based (N type), the second one was modified sulfonate based (M type) and the third one was polycarboxylate based (P type). Properties of those chemical admixtures are given in Table 3.

Mineralogy of Bayburt stone was studied earlier by Tekin [18]. He reported that there are some zeolite crystals such as clinoptilolite and heulandites in BS. Pozzolans are a broad class of siliceous or siliceous and aluminous materials which, in themselves, possess little or no cementitious value but which will, in finely divided form and in the presence of water, react chemically with calcium hydroxide at ordinary temperature to form compounds possessing cementitious properties. The pozzolanic properties of Bayburt stone were studied by Çavdar and Yetgin [19] and they reported compressive strengths ranging from 6.7 to 11 MPa.

Waste BS was prepared as aggregate by crushing in a laboratory crusher. In the production of LCs, the Fuller curve was preferred as aggregate gradation. The maximum aggregate size was selected as 8 mm. Particle size distributions of aggregates are given in Table 4.

Specific gravity and water absorption were determined according to the ASTM C127 [20] and ASTM C128 [21] standards. Moreover, compressive strength of white BS was determined as 35 MPa by breaking the cubic samples sized 50 × 50 × 50 mm. Physical properties of white BS are listed in Table 5.

Table 5. Physical properties of white BS

Properties	0 – 4 mm sieve	4 – 8 mm sieve
Water absorption, %	19.3	16.1
Dry specific gravity	1.65	1.61
Specific gravity of saturated and dry surface	1.96	1.86

Fig. 1 shows an image and porosity analysis by using Mercury Intrusion Porosity (MIP) method of the white BS.

Fig. 1. MIP analysis result of the BSW

In Fig. 1 we see micro and nano pores; their sizes range between 40 nm and 8 µm. Moreover, thermal conductivity of the white BS is determined as ≈ 0.58 w/mK by using the hot plate method.

Table 1. Physical and mechanical properties of OPC

Compressive strength, MPa			Flexural strength, MPa			Setting times, hour		Soundness, mm	Specific gravity, g/cm^3	Blaine, cm^2/g
2nd day	7th day	28th day	2nd day	7th day	28th day	Initial	Final			
25.9	38.6	58.2	3.8	5.7	7.2	2.24	3.1	1	3.13	3482

Table 3. Technical properties of chemical admixtures

	N type	M type	P type
Major component of admixtures	Naphthalene sulfonate based	Modified sulfonate based	Polycarboxylate ether based
Color	Brown	Dark brown	Brown
pH	6.5 – 8	7 – 9	5 – 7
Density, kg/l	1.15 – 1.21	1.21	1.08 – 1.14
Chloride content, %	< 0.1	< 0.1	< 0.1
Alkaline content, %	< 10	< 7	< 3
Ratio of solid content, %	35	35	35

Table 4. Particle size distributions of aggregates

Aggregate type	Sieve size							
	9.5 mm	4.75 mm	2.36 mm	1.18 mm	600 µm	300 µm	150 µm	75 µm
	Percentage passing							
BS	100	70	50	35	25	18	12	9

White BS is a rock in which its surface has porphyritic texture, and it has quartz and alkali feldspar, and it also contains rich deposits of zeolitic mineral such as clinoptilolite and heulandite (a clay mineral) as found by Tekin using XRD [18]. The w/c ratio was adjusted according to S1 type consistency of the concrete. However, due to the difficulties of compacting of LC type concretes, we tried to find S4 type slump level by trying different plasticizer so that the concrete wall blocks could be produced economic and prefabricate. Thus, each LC mixtures were prepared with 150, 200 and 250 kg/m^3 cement. Specimens were produced with different ratios and types of plasticizers. We wanted also to determine compatibility between cement and plasticizer. Firstly, N type plasticizer was used with 1.8 %, 2 %, 4 %, 6 %, 10 % and 20 % by weight to the cement amount to produce LC type specimens. Secondly, P type plasticizer and after that M type plasticizer were used. The LC mixtures were prepared by means of the pan type mixer according to mix design presented in Table 6.

While the concrete mixtures were being prepared, initially the water was added to the aggregate in each concrete mix and the combination mixed for 1 min. Following that, mixes were hold in the mixer till aggregates became saturated. When aggregates were being saturated by water, cement was added to the mixture and mixed again for 1 min. Slump test was the first performed and recorded. After that, the prepared fresh concretes were placed into plastic molds, cylindrical shape Ø 10/20 cm sized, in three stages and were compacted on a horizontal vibration table for 1 min. After the samples had been kept 24 h in the laboratory under a wet cloth, they were taken out from their molds. Then the specimens were placed in a steam curing cabinet at 70 °C for 7 days as shown in Fig. 2. After LC specimens were taken out from the steam curing cabinet, they were placed in a standard water curing cabinet at 22 °C till 28th day. After 28 days, specimens were taken out from the curing cabinet and kept in the laboratory condition at 20 ± 2 °C and 50 ± 5 % relative humidity (R.H.). The compressive strength tests were performed on three samples on 3rd, 7th, 28th, 90th and 1800th day. Scanning electron microscopy observations were performed with FEI Nova Nano SEM 450 on 28th day. Water absorption tests were performed on 90th day.

In the last stage, the best specimen were selected for final tests such as freeze-thaw resistance, thermal conductivity, elevated temperature effect, capillary action and toughness calculation. A group of LC14 specimens was selected on the basis of a high compressive strength on 3rd day, low chemical admixture level with 250 kg/m^3 cement and good workability. Freeze-thaw resistance testing was performed according to the ASTM C666 standard [22]. Cubic specimens with the sizes of 10 × 10 × 10 cm were prepared for elevated heat exposure tests, and prismatic specimens with the sizes of 10 × 10 × 40 cm were prepared for capillary action testing according to the mixture design of the LC14 type concrete. Thermal conductivity tests were performed according to the hot plate method developed by Soroka and coworkers [23] on specimens sized of 1 × 2 × 4 cm from the LC14 type mixture. Elevated heat exposure tests were performed on the LC14 type concrete specimens at 100 °C, 300 °C, 500 °C and 700 °C on 7th day. During the heat exposure tests, the specimens were kept in a furnace for 2 hours after the predefined temperature was achieved, and then until the room temperature was reached by natural cooling. Compressive strength tests were done on all LC14 specimens after heat exposure. Strain-stress measurements were performed under compression. Moreover, Excel software was used to look for a relation between strain-stress and thermal results. The areas under the curves were calculated with the help of AutoCAD software to calculate toughness values.

Capillary absorption tests were performed according to ASTM C1585 [24], on LCWB samples with size of 10 × 10 × 40 m in a stand shown in Fig. 2.

Table 6. Mixture proportions

Code	Cement, kg/m^3	BT 0-4, kg/m^3	BT 4-8, kg/m^3	Water, kg/m^3	W/C	W/B	Plasticizer type	Plasticizer ratio, %	Air-entraining admixture, %
LC1	150	584	831	207	1.38	1.00	N	1.8	–
LC2	150	573	816	205	1.37	0.99	N	2.0	–
LC3	150	576	820	202	1.35	0.97	N	4.0	–
LC4	150	578	823	199	1.33	0.96	N	6.0	–
LC5	150	584	831	192	1.28	0.92	N	10	–
LC6	150	625	890	139	0.93	0.66	N	20	–
LC7	150	590	840	184	1.23	0.88	P	2.5	–
LC8	150	638	908	123	0.82	0.57	P	4.0	–
LC9	150	599	853	172	1.15	0.82	M	2.5	–
LC10	150	622	887	142	0.95	0.67	M	2.5	0.5
LC11	200	595	847	162	0.81	0.62	M	2.5	0.5
LC12	200	595	847	162	0.81	0.62	M	2.5	1.0
LC13	250	551	784	202	0.81	0.66	M	2.5	0.5
LC14	250	551	784	202	0.81	0.66	M	2.5	1.0

Fig. 2. Capillary absorption testing stand

3. RESULTS AND DISCUSSION

The testing results are summarized in Table 7 and also in Fig. 3 and Fig. 4.

As can be seen in Table 7, for the specimens with N type plasticizer, with increasing pasticizer concentration the compressive strength increases. However, the increases between 3rd to 90th days are not that significant for LC1 – LC4, this due to the lower cement dosage.

Steam curing is known to be important in the concrete technology. Especially, if pozzolanic material is used in a concrete along with steam curing between 60 to 80 °C, the concrete compressive strength can reach on 7th day 90 % of its value on 28th day [25]. Compressive strength values of the LC11 – LC14 (200 and 250 kg/m^3 cement) increased 20 – 50 % on 90th day with respect to the 7th day.

In Fig. 3 we show the dependence of the compressive strength on the admixture ratio. According to Fig. 3, there is a strong correlation between the plasticizer ratio and the compressive strength. However, using chemical admixture in 20 % ratio is too high; there is a negative effect on setting time and cost. Moreover, N type plasticizer did not reduce the w/c ratios sufficiently for the same workability in the LC1 – LC6 group because of lower cement dosages. Therefore, when the cement dosages in LCs were below 150 kg/m^3, the plasticizer effects on the properties of LC1 – LC6 were relatively small.

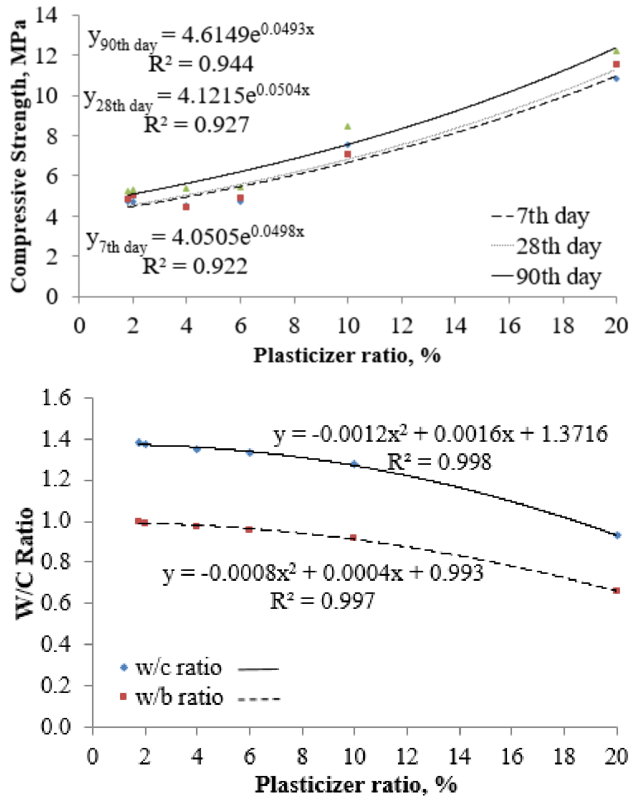

Fig. 3. a – relation between compressive strength and admixture ratio of LC1 to LC6; b – relation between w/c ratio and admixture ratio for LC1 to LC6

We see in Fig. 4 that the water absorption values for LCs 1 – 8 are between 10 and 18 % because of low workability of LCs. The compressive strength values are related to the water absorption values. Unit weights and water absorption ratios for the LCs are also listed in Table 7. The unit weights are between 1.43 and 1.60 kg/dm^3. Apparently water absorption and unit weights decrease as the admixture ratios increase for the LC1 – LC6, this due to relatively low w/c ratios. The increases in the admixture ratio do not change the unit weights of hardened concrete significantly.

Table 7. Test results

Code	Cement kg/m^3	SP type	Slump, cm	Unit weight, kg/dm^3	Water absorption, on 90th day	Average compressive strengths, MPa				
						3rd day	7th day	28th day	90th day	1800th day
LC1	150	N	3	1.49	0.18	4.1	4.7	4.9	5.2	7.2
LC2	150	N	4	1.47	0.17	4.2	4.7	5.1	5.3	8
LC3	150	N	4	1.46	0.17	4	4.5	4.5	5.3	8.9
LC4	150	N	3	1.50	0.16	4.4	4.7	5	5.5	8.5
LC5	150	N	4	1.50	0.15	6.9	7.5	7.1	8.4	12.1
LC6	150	N	4	1.55	0.11	8.4	10.8	11.6	12.2	18.2
LC7	150	P	4	1.58	0.12	3.9	4.1	4.9	5.1	7.7
LC8	150	P	4	1.60	0.11	3.9	4.1	4.5	5	6.5
LC9	150	M	4	1.59	0.12	4.5	4.8	5.2	5.6	7.7
LC10	150	M	4	1.54	0.10	5.2	5.4	5.8	6.1	9.4
LC11	200	M	4	1.44	0.11	5.1	5.8	6.1	6.4	10
LC12	200	M	7	1.43	0.13	5	5.2	5.8	6.2	10.6
LC13	250	M	8	1.52	0.10	6.6	7.4	8.3	9	14.3
LC14	250	M	19	1.46	0.12	8.9	10.9	12.4	13.3	21.4

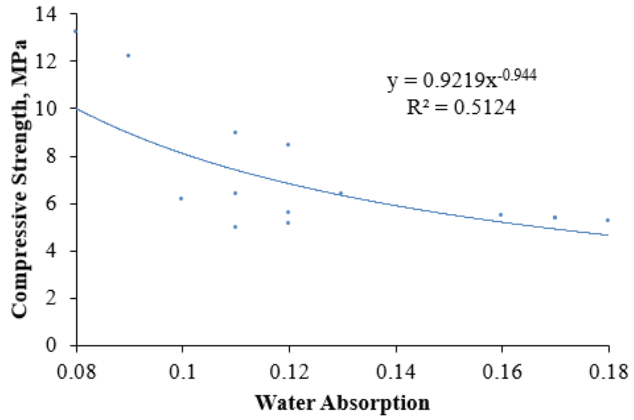

Fig. 4. Relations between compressive strength test results and water absorption of LC's

The water demand of fresh LC type concretes decreases as the quantity of admixture increases. However, as also seen in Table 7, the decreases vary with changing the plasticizer ratio. In LC1 to LC6 specimens, when the ratio of admixture was increased from 10 % to 20 %, the w/c and w/b ratios decreased by 35 % and 26 %, respectively. This can be explained by the existence of an enhanced interface zone between cement and aggregates at lower w/c ratios. We also note that the maximum calcium silicate hydrate (CSH) bonding structure can be formed by rapid steam curing [1]. As shown in Table 7, minimum requirements for compressive strength and unit weight are fulfilled by the LC5, LC6, LC13 and LC14 types of concretes according to the specification of wall elements. However, LC5 and LC6 have high plasticizer ratio and are not cost effective. LC13 is good choice for producing LCWB elements, but workability is lesser than for the LC14 type mix design. Therefore, LC14 mix design was selected as optimal for production for LCWB elements. The elements were manufactured as shown in Fig. 5.

Fig. 5. LC block wall elements produced from mix design of LC14 type concrete

Microscopic observations of LC14 type concrete are shown in Fig. 6.

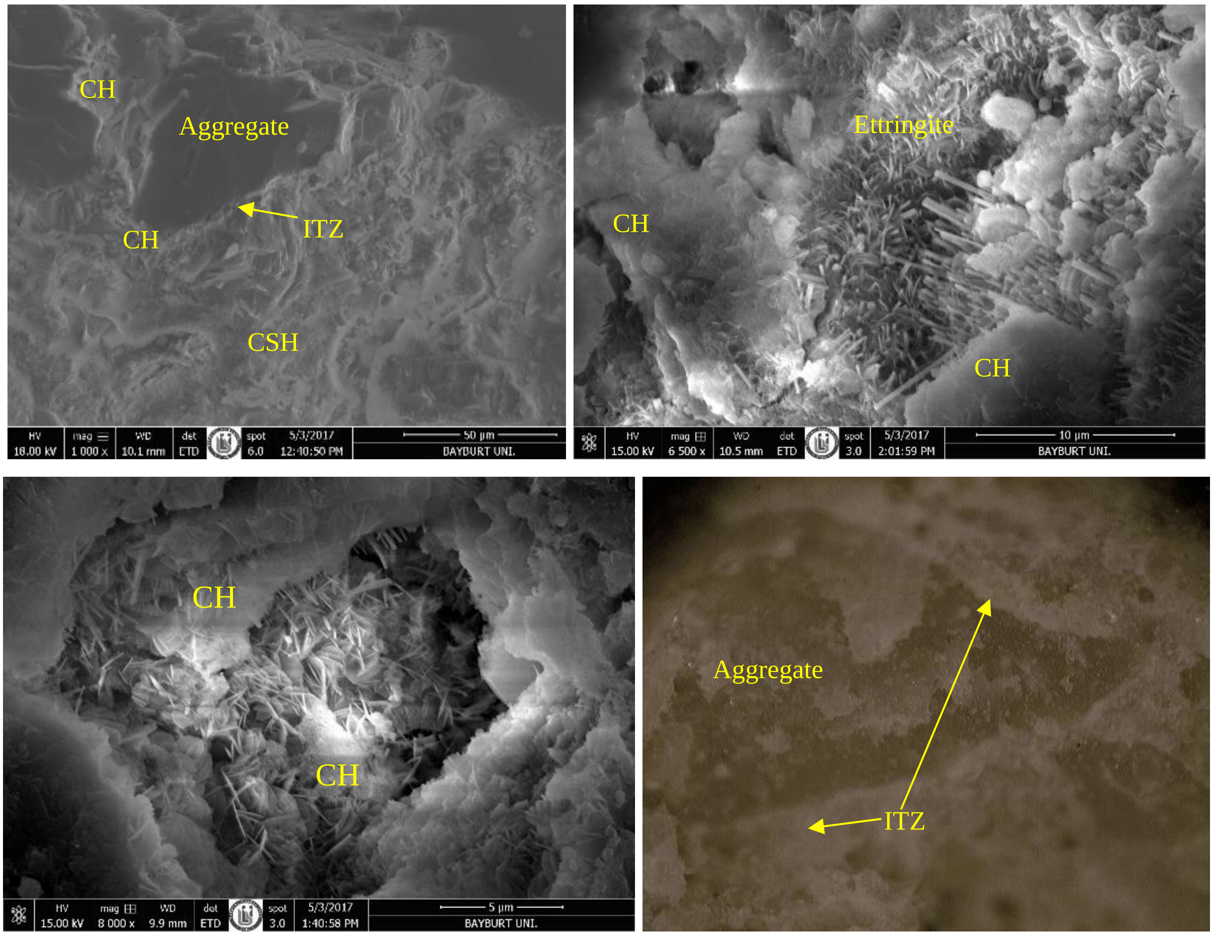

Fig. 6. SEM and optical microscope images of LC14 type concrete on 28th day; CH is calcium hydroxide, ITZ is the interfacial transition zone

According to Fig. 6, there are large amounts of calcium hydroxide (CH) particles on surfaces and in voids of LC14 type concrete. Dense ettringite and CH structures can be also seen on 28th day. Thus, the pozzolanic activity of BS did not produce large effects on 28th day. However, compressive strength gain continued due to that activity of BS. LC14 type concrete gained compressive strength roughly 61 % in 5 years. Moreover, compressive strength of the other type concretes increases between 40 % – 60 % in 5 years. Because CEM I type cement from Askale Cement factory we have used has 70 % ratio of C_3S according to Bogue formula, large numbers of CH particles are made up by the hydration process. Those particles increase the pozzolanic activity of BS, hence an increase in compressive strength.

Capillary absorption test results for the LC14 type concrete according to the ASTM C1585 are shown in Fig. 7. In that Figure "I" is the capillary absorption value which changes with time. To calculate the absorption value from the test, when the point of slope change, m_t (the change in specimen mass in grams, at the time t), a (the exposed area of the specimen, in mm^2) and d (the density of the water in g/mm^3) values are recorded, and then the absorption can be calculated [29] as:

$$I = m_t/(a \times d). \tag{1}$$

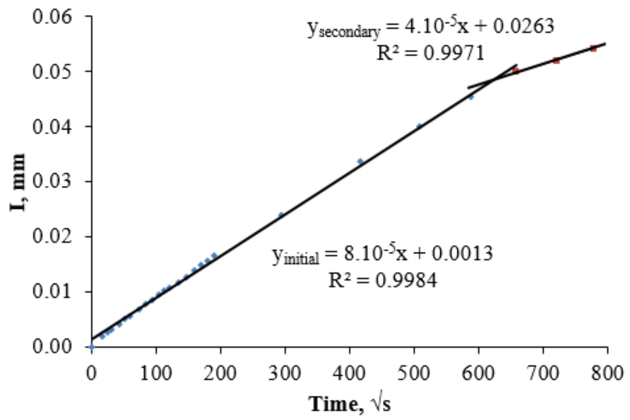

Fig. 7. Diagram of capillary absorption rate for the LC14 type LCWB

Initial capillary absorption (sorptivity) rate and secondary absorption rate for the LC14 type concrete are 8.30×10^{-5} and 5.82×10^{-5}, respectively. Capillary voids are more active in this respect in the initial phase due to their small diameter. Therefore, there is a change of slope point and the slope to the right of that point is lower than slope of the initial capillary absorption. According to these results, capillary absorption rate of the LC14 type concrete was 10 times higher than in the conventional structural concretes with 0.38 – 0.42 w/c ratio [23].

Slump behavior of LC14 type concrete specimens was observed as plastic - even at high level w/c ratios - due to the high cohesion of white BS. Therefore, 81 % w/c ratio was used for preparing the LC14 concrete specimens with 19 cm slump, while the compressive strength on 3rd day was obtained as 8 MPa with the help of hot steam curing. The results of thermal conductivity tests on LC14 type concrete are given in Table 8.

The average thermal conductivity value for the samples listed in Table 8 is 0.55 W/mK. The standard requires values below 0.75 W/mK.

Compressive testing results of LC14 type LCWB are presented in Fig. 8 as stress vs. strain values for several temperatures, after heat exposures at 100 °C, 300 °C, 500 °C and 700 °C.

Table 8. Heat transfer parametr values of the wall elements

Code	W/mK
LC14_1	0.549
LC14_2	0.553
LC14_3	0.550
LC14_4	0.551
LC14_5	0.548
LC14_6	0.549
Average value	0.550
Standard deviation	0.0018

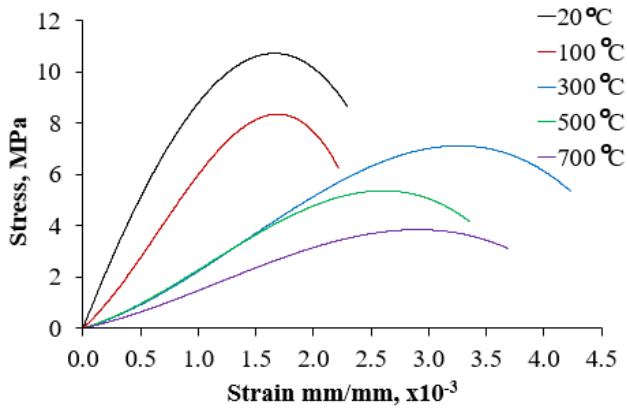

Fig. 8. Effect of elevated temperature on stress-strain relationship of LC14 type wall element in compressive testing

There are several definitions of toughness, but the most often used is: the surface area under the stress vs. strain diagram [28, 26]. Toughness values of the LC14 type specimen were calculated from stress-strain curves. The compressive strength, compressive modulus and compressive toughness values of the LCWB elements are provided in Table 9.

Table 9. Compressive properties of block element exposed to elevated temperature

Temperature, °C	Compressive strength, MPa	Young's modulus, GPa	Compressive toughness index, W_{cu}	Stress – strain properties			
				A_1	A_2	$\varepsilon_c \times 10^{-3}$	f_c
20	10.9	7.91	42.02	2.76	1.52	1.65	10.9
100	8.4	6.93	49.41	1.87	1.02	1.70	8.35
300	7.1	6.39	50.83	3.02	1.52	3.25	7.10
500	5.4	5.57	51.24	1.83	0.91	2.60	5.40
700	3.8	4.71	50.78	1.47	0.70	2.90	3.85

A_1 values in MPa are the areas until the first crack point on the stress-strain curves. A_2 values also in MPa are the areas between the first crack point and the end point on the same curves. ε_c values are deformations corresponding to the maximum compressive strengths while f_c are the peak points corresponding to those maxima. Compressive toughness index W_{cu} values are calculated [29] as

$$W_{cu} = \frac{\Omega}{A \cdot l}, \quad (2)$$

where Ω_u is the area under the load-deformation curve with the vertical deformation in N·mm; A is the area of the specimen subjected to uniaxial compression while l is the specimen height.

Young moduli of the LCWB elements were calculated according to the ACI 318 standard [27]. As it can be seen in Table 9, compressive strength and compressive Young modulus values decrease with heat exposure. The compressive toughness W_{cu} is higher at elevated temperature than at 20 °C – while its values do not change significantly between 100 and 700 °C. Possibly raising the temperature to 100 °C increases the ductility significantly while further temperature increases have only small effects.

4. CONCLUSIONS

The ZT can be used as an aggregate and pozzolanic material in LWCB with low cement content. Although 150kg/m^3 can be enough for producing LWCB, consistency was not sufficient for industrial manufacturing. Lower cement content about 150 kg/m^3 is not convenient to produce LWCB due to freeze-thaw resistance. Minimum cement content was observed as 250 kg/m^3. Compressive strength of LWCB achieved to 8.9 MPa and 21.4 MPa at 3rd and 1800th days, respectively. Compressive strength is sufficient for the structural wall elements in the size of 10×20×40 cm. With that size, LWCB formed as 11.68 kg, and if desired, the product can be formed with holes and the weight of its can be reduced by this method. LWCB is also durable for heat exposure till 700^{o}C and its toughness is very good for a block wall element. Freeze-thaw resistance of the LWCB is good enough for structural wall elements as well. Thermal conductivity of the LWCB element provide sufficient value for the wall elements. When it comes to the cost of LWCB, it is better than an aerated concrete and a masonry hollow blocks; however, it is expensive for clay hollowed brick. Nevertheless, casualty rate of LWCB is lower than the clay brick. With this study, the new LWCB was produced by different process and some of way of its were better than the others.

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