

Lightweight Concrete with Aggregates Made by Using Industrial Waste

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The disposal and treatment of solid and hazardous industrial waste is quite expensive for any industry; therefore it brings challenges to find a solution that permits to obtain new, usable products by waste utilization in a technically and economically sustainable as well as environmentally friendly way.

The production of lightweight concrete by using aggregates made by industrial by-products and hazardous solid waste such as expanded fly ash, slag, sludge etc. is well known. This research provides possibilities to reuse waste called non-metallic product (NMP) from aluminium scrap recycling factories for the manufacturing of lightweight expanded clay aggregates and lightweight concrete. Characterization of NMP is described in the preliminary publications (Bajare et al. 2012).

The manufacturing cycle of lightweight expanded clay aggregates were simulated in laboratory by sintering the clay - waste mixes in the rotary furnace up to 1200°C. Lightweight expanded clay aggregates with rather different pore structure were obtained due to slight variations of mixture composition and sintering temperature. Produced aggregates were with bulk density from 320 kg/m³ to 620 kg/m³. Different types of lightweight aggregates were used to produce lightweight concretes. Mechanical, physical and thermal conductivity tests were performed for hardened concrete specimens according to standard procedures.

Keywords: *lightweight concrete, expanded clay aggregate, industrial waste.*

1. Introduction

Lightweight aggregates are granular and porous materials with a bulk density in a range of 280 kg/m³ to 1100 kg/m³, depending on the type and grading size (Owens, 1993). For their low density, good thermal and acoustic insulation, and good fire resistance properties, lightweight aggregates have become a focus of interest. They are an essential component in a variety of building materials such as prefabricated structural units, lightweight concretes, especially in high-rise buildings, as well as track ballasts and road coatings, along with bituminous materials and other geotechnical applications (Babu and Babu, 2004). Lightweight concrete can be defined as the product resulting from the binding of lightweight aggregate particles or fragments with a binder, usually artificial cement, and water. The term *lightweight concrete* is used for concrete with a density of less than 1800 kg/m³ (Mehta and Monteiro, 2006).

Quite often, the aggregates comprise the weakest component within the concrete. The greater the aggregate strength and density, the higher will be the concrete strength. Factor like the water–cement (w/c) ratio also has a great influence on the concrete properties (Short and Kinniburgh, 2007). When the water/cement ratio of concrete increases, the number of pores within the cement paste and in the

aggregate/cement paste interfacial zone increases as well. An increase in pore numbers within the cement paste and in the aggregate/cement paste interfacial zone leads to a corresponding decrease in concrete strength (Tommy and Tang, 2007).

The disposal and treatment of solid and hazardous industrial waste is quite expensive for any industry, therefore it brings challenges to find a solution that permits to obtain new, usable products by waste utilization in a technically and economically sustainable as well as environmentally friendly way. The production of lightweight concrete by using aggregates made by industrial by-products and hazardous solid waste such as expanded fly ash, slag, sludge etc. is well known (Naik and Moricioni, 2006; González-Corrochano et al. 2011; Shinzato and Hypolito, 2005). In study lightweight aggregate was sintered by incorporation of sludge which was a gas former to the mixture of clay that is conformed in spherical form and heat treated at high temperatures around 1100-z°C (Pinto et al. 2004). The voids are generated by the combustion or gasification of the waste included in mass of the aggregate.

This research provides possibilities to reuse waste called non-metallic product (NMP) from aluminium scrap

recycling factories for the manufacturing of lightweight expanded clay aggregate and lightweight concrete. The consumption of aluminium waste is rising continuously worldwide, which is great stimulus for developing a non-waste technology (Shen and Forssberg, 2003; Lucheva et al. 2005; Samuel, 2003).

This work is based on a previous research, where investigation on how the type of clay, the type and amount of NMP and the sintering temperature affect the properties of the sintered lightweight aggregate. It was concluded that the maximum expansion temperature of lightweight aggregate increases proportionally to a higher amount of the NMP proportion in the clay composition, i.e., every composition has its own maximum expansion temperature. The NMP here was considered as foaming agent (LVS, 2002).

The goals of this experimental work are: 1) to produce lightweight aggregate of NMP and clay in a laboratory rotary kiln in different sintering temperatures; 2) to produce lightweight concrete by using them. The mechanical, physical properties for the produced aggregates and lightweight concrete will be analyzed as well.

2. Methods

Raw materials

In the current study lightweight expanded clay aggregates and NMP from aluminium scrap recycling factories in different compositions. The chemical composition of clay and NMP was determined according to LVS EN 196-2 with the sensibility of ± 0.5 wt% (Table 1) (Bajare et al. 2012), were produced from clay with a high content of carbonates.

Table 1. Basic chemical composition of clay and NMP (wt%)

	Clay	NMP
Ignition loss, 1000°C	13.60	6.21
Al ₂ O ₃	14.34	63.19
SiO ₃	50.22	7.92
CaO	8.54	2.57
SO ₃	0.07	0.36
TiO ₂	0.56	0.53
Na ₂ O	0.43	3.84
K ₂ O	3.09	3.81
MgO	3.07	4.43
Fe ₂ O ₃	5.74	4.54
Others		>2.60

The X-ray diffraction analysis (XRD) was used for determination of changes in the mineralogical composition of NMP during the heat treatment. According to the XRD of NMP, the following toxic impurities were eliminated by heat treatment at the temperature of 1100°C: aluminium nitride (AlN), iron sulphite (FeSO₃) and aluminium chloride (AlCl₃) (Table 2). Emissions of gases (the smell of ammonia was detected) during high-temperature treatment of NMP are used as initiator to create an extra porous structure of the sintered ceramic bodies.

The clay with high carbon content was mixed with NMP in two different proportions. Obtained compositions were named LA and LB, corresponding to 9.1% and 23.1% of NMP by weight, respectively. This kind of selection was on the basis of the previous investigations (Bajare et al. 2012).

Table 2. Basic mineral composition of clay and NMP

Clay	NMP	NMP (treated at 1100°C)
SiO ₂	Al ₂ O ₃	Al ₂ O ₃
CaCO ₃	FeAlO ₃	FeAl ₂ O ₄
KAl ₂ (Si ₃ AlO ₁₀)(OH) ₂	MgAl ₂ O ₄	MgAl ₂ O ₄
Na(K)AlSi ₃ O ₈	SiO ₂	α -SiO ₂
Al ₂ Si ₂ O ₅ (OH) ₄	Al	SiO ₂
CaMg(CO ₃) ₂	FeSO ₃	
	AlN	
	AlCl ₃	
	Al(OH) ₃	

Production of lightweight expanded clay aggregates

The clay and NMP mixtures were milled and homogenized with planetary ball mills. The particle size of the mix was determined by Particle Size Analyzer ZetaPlus. Effective diameter of mix was 54 μ m, median diameter – 8.7 μ m, but mean diameter – 11.3 μ m. A controlled amount of water of 20 – 25% was added to the homogenized mixtures. Green pallets with a spherical shape and diameter from 5 to 10 mm were prepared by granulating technique. Next step was the drying process in room temperature for 24 h and, subsequently, dried in an oven at 105°C for 48 h.

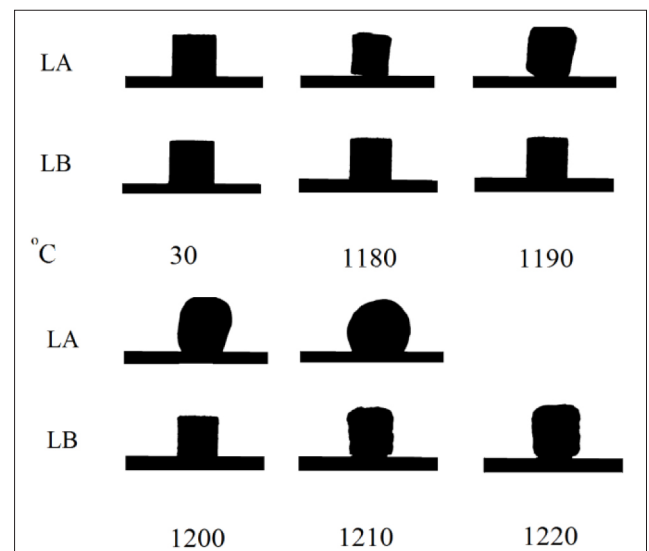


Fig. 1. Melting behavior of the base powder mixture LA and LB

Prior to sintering the dry pallets in laboratory rotary kiln, determination of the melting behavior of the base powder mixture LA and LB using Hesse® heating microscope was done (Fig. 1). The heating rate till 500°C was 80°C/min, but till 1350°C – 15°C/min. It has results in the rotary kiln indicated that the sintering starts at a temperature, which is 20 – 30°C lower than determined in the heating microscope. The temperature for the kiln was set to 1180°C for both

aggregate compositions. The mixture LA in this temperature expanded more than mixture LB sintered in the same temperature. It can be concluded that in the same temperature with less NMP content in the mixture, lightweight expanded clay aggregate with lower density can be obtained.

Sintering of the pallets was carried out in a rotary kiln made by the heat treatment equipment company Keramserviss (Fig. 2). The length of the tube is 200 cm, its internal diameter – 6.7 cm. The rotary kiln has three zones with a thermocouple in each, where the central zone is with the highest temperature. The temperature can be set manually by the user. The pallets in the kiln were placed in a continuous flow by using special equipment. In the entering zone the pallets were gradually heated to the sintering temperature to avoid their damage and uneven pore distribution. The whole sintering process ranged from 10 to 15 minutes until the necessary viscosity was achieved to generate and trap the gases inside the lightweight expanded clay aggregate. Due to the rotating speed 20 rpm and the constant kiln incline of 1°, the granules moved through all heating zones. The produced granules were from 4 to 11.2 mm in diameter.



Fig. 2. Laboratory rotary kiln for lightweight aggregate production

Lightweight concrete design

In order to obtain comparative data, the experimental lightweight concrete was produced by using both

laboratory produced lightweight aggregates LA and LB and commercially available A1, A2 and B1. Ordinary Portland cement CEM I 42.5 N was used as a binding agent. Sand from 0–4 mm was used as an additional aggregate for better particle distribution in the concrete composition. In some compositions undensified commercial silica fume product (SF) Elkem microsilica 971U was used. Concrete compositions were produced with the water cement ratio of 0.46. The first one was designed with a cement content of 348 kg/m³, where the main variable in the concrete composition was lightweight expanded clay aggregate, LA, A1, A2, LB and B1 and was marked with a prefix C before the aggregate marking. Concrete compositions with aggregates LA, A1 and A2 were named as low strength concrete. Concrete compositions with aggregates LB and B1 were named as high strength concrete accordingly. The second concrete composition was produced with an increased amount of cement – 425 kg/m³, SF, additional admixture superplasticizer and varied with aggregates LB and B1. They were named as high strength lightweight concrete with silica fume and were marked with a prefix CC before the aggregate marking. The lightweight expanded clay aggregates were used in a pre-wetted condition so that water content in the cement paste does not change by water absorption of the aggregates. Concrete compositions are summarized in Table 3.

Concrete compositions were mixed with high speed paddle mixer according to the following procedure: first, dry components were mixed for 1 minute, then 2/3 of water amount was added and mixed for 1 minute. During the next step of mixing the remaining water was incorporated together with admixtures.

To determine the mechanical and physical properties concrete specimens (4 × 4 × 16 cm) were prepared by using steel moulds. Consolidation was done by using vibrating table. Nine specimens were prepared for each composition. The specimens were cured in curing room. The compressive and flexural strength was determined at the age of 3 and 28 days according to EN 12390. The tests were performed 24 h after the specimens were removed from the curing room. Physical properties, like water absorption and bulk density, were determined after 28 days.

Table 3. The amount of materials for 1m³ of concrete mixture, kg

Materials	Low strength lightweight concrete			High strength lightweight concrete		High strength lightweight concrete with silica fume	
	CLA	CA1	CA2	CLB	CB1	CCLB	CCB1
Portland cement CEM I 42.5 N	348	348	348	348	348	425	425
Sand (0 - 4 mm)	822	822	822	822	822	829	829
LA	232	-	-	-	-	-	-
LB	-	-	-	445	-	341	-
A1	-	227	-	-	-	-	-
A2	-	-	230	-	-	-	-
B1	-	-	-	-	568	-	436
Silica fume	-	-	-	-	-	55	55
Admixtures - superplasticizer	2	2	2	2	2	7	7
Water	160	160	160	160	160	195	195
Total	1564	1559	1562	1777	1900	1852	1947

The thermal conductivity of 30 × 30 × 5 cm thick plate specimens was measured using a heat flow meter (LaserComp® Fox 600). The specimens were tested in air-dry conditions.

3. Results and discussion

Physical and mechanical properties of the lightweight expanded clay aggregates

In order to compare the produced lightweight expanded clay aggregates LA and LB with the commercially available alternatives, different lightweight concrete compositions containing different aggregates were prepared. Commercially available lightweight expanded clay aggregates, named A1, A2 were compared with produced aggregate LA and B1 with LB. The bulk density and particle density of aggregates were measured in accordance with EN 1097-3 and EN 1097-6. Crushing strength was done by a standard method mentioned in GOST 10268-80 for a relative comparison between the aggregates. The bulk, particle density and crushing strength for these aggregates are shown in Table 4 and 5.

Bulk density of aggregates is ranging from 320 kg/m³ to 360 kg/m³, where the produced aggregate LA has the lowest bulk density of 320 kg/m³ (Table 4). Higher difference between the aggregates is observed in crushing strength, where LA has 0.81 MPa, but A1 and A2 has 1.36 MPa and 1.49 MPa, respectively.

Table 4. Physical and mechanical properties of lightweight expanded clay aggregates

	Bulk density, kg/m ³	Particle density, kg/m ³	Crushing strength, MPa
LA	321.1	600.0	0.81
A1	360.5	588.5	1.36
A2	362.2	594.2	1.49

LB has lower bulk density (620 kg/m³) comparing to the bulk density of aggregate B1 (830 kg/m³). Aggregate B1 is with higher crushing strength of 12.21 MPa, where the produced aggregate LB has 4.21 MPa. The aggregate density is one of the main criteria, which is taken into account measuring the aggregate quality and thereafter its influence on the mechanical behavior of lightweight concrete.

Table 5. Physical and mechanical properties of lightweight expanded clay aggregates

	Bulk density, kg/m ³	Particle density, kg/m ³	Crushing strength, MPa
LB	624.2	1154.2	4.21
B1	834.3	1471.7	12.21

Water absorption for the aggregates was measured after 30 minutes, 1, 24 and 48 hours (EN 1097-6). The results are shown in Fig. 3. In the first 30 minutes aggregates absorb about 80% of the total amount of water absorbed in 48 hours. For commercially available aggregates A1 and A2

the water absorption after 48 hours (~18%) is higher than for the produced aggregate LA (~12%). The produced aggregate LB showed lower water absorption after 48 hours (~9.5%) than B1 (~12%), which means that less additional water will be necessary to add in the concrete mixing process.

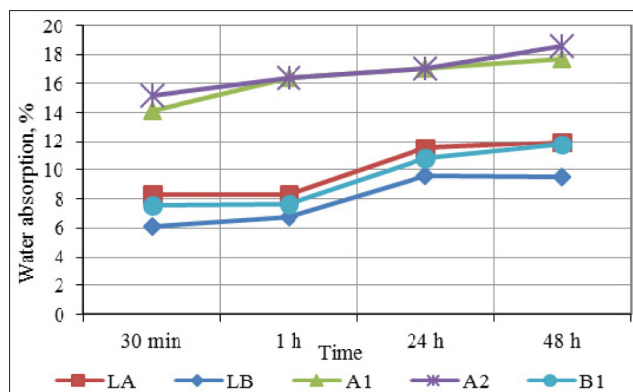


Fig. 3. Water absorption of aggregates vs. time function



Fig. 4. Low strength lightweight concrete specimen and aggregates LA

Physical and mechanical properties of the lightweight concrete specimens

Density and water absorption of lightweight concrete specimens are shown in fig. 5 and 6. Low strength concrete CLA, CA1 and CA2 bulk density ranged from 1550 kg/m³ to 1600 kg/m³ (Table 6). High strength lightweight concrete CLB, CB1 and CCLB samples showed bulk density under 2000 kg/m³, ranging from 1800 to 1920 kg/m³, but concrete composition CCB1 showed result 2020 kg/m³ (Table 7). A clear trend was observed that lower bulk density concrete samples showed higher water absorption. For concrete CLA, CA1, CA2, CLB and CB1 water absorption varied from 7.5% to 8.6%, but for high strength lightweight concrete with SF the result was lower ranging from 4.3% to 4.6%. Despite the fact that water absorption of lightweight aggregates A1 and A2 was almost two times lower, the influence to the concrete water absorption was insignificant (difference between CLA and CLA1, CLA2 was 0.2%–0.3%). It might be explained by the pre-wetting of the lightweight aggregates, because in this case the free water in fresh concrete is not taken away by the aggregates, thereby not influencing the porosity and water absorption of concrete.

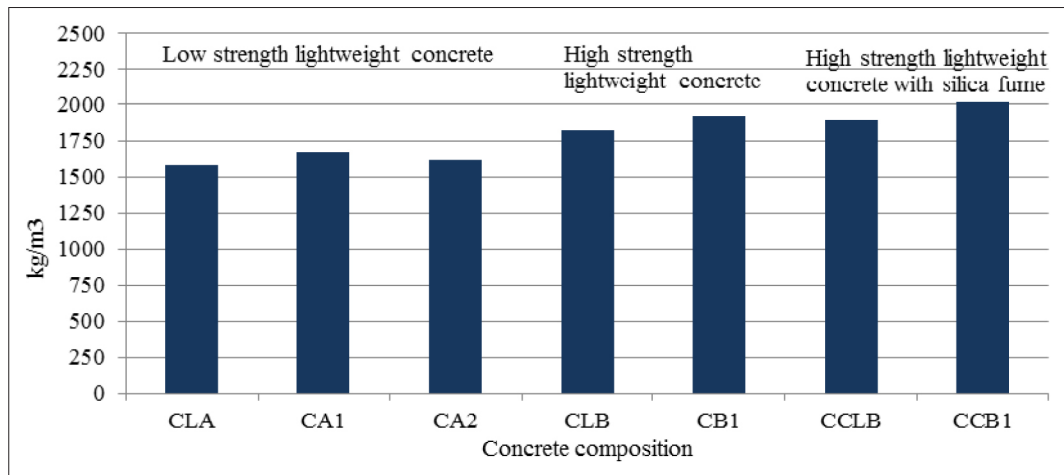


Fig. 5. Bulk density of lightweight concrete, kg/m³

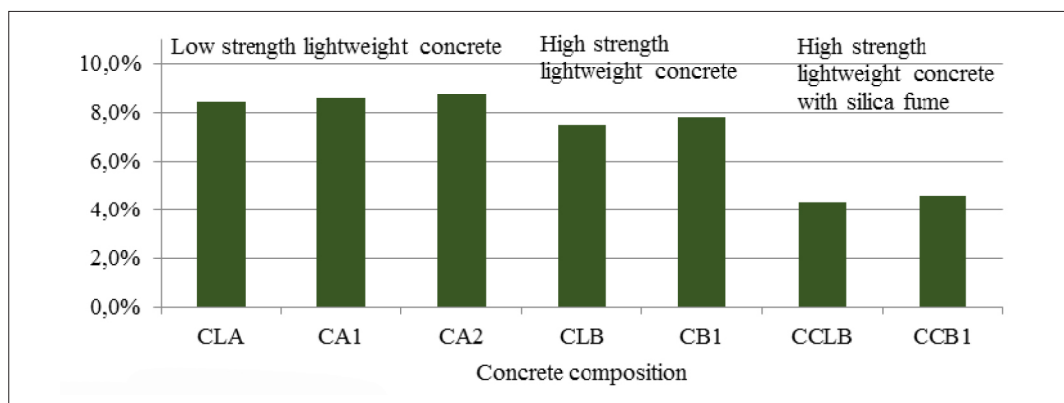


Fig. 6. Water absorption of lightweight concrete

Table 6. Bulk density and water absorption of low strength lightweight concrete

Concrete composition	Bulk density, kg/m ³	Water absorption, %
CLA	1580	8.4%
CA1	1670	8.6%
CA2	1620	8.8%

Table 7. Bulk density and water absorption of high strength lightweight concrete with and without SF

Concrete composition	Bulk density, kg/m ³	Water absorption, %
CLB	1800	7.5%
CB1	1920	7.8%
CCLB	1890	4.3%
CCB1	2020	4.6%

The results of concrete compressive and flexural strength at 3 and 28 days are shown in Fig. 7 and 8. Comparing the aggregate crushing strength in Table 4 and 5, it is concluded that the achieved level of concrete strength was directly proportional to the aggregates crushing strength as well as to the aggregate density. High strength concrete specimens with SF, CCLB and CCB1

showed higher strength after 28 days than CLB and CB1, respectively. However, it was lower after 3 days, which might be explained by higher admixture content delaying the hydration processes in cement paste and SF addition (it increases the final strength due to pozzolanic reactions). For concrete specimens CLB and CCLB with produced aggregate LB compressive strength after 28 days was 32 MPa and 43 MPa reaching 34 % increase. As it was expected, concrete specimens with a use of B1 as aggregate showed higher compressive strength after 28 days, where for concrete specimens CB1 and CCB1 it was 54 MPa and 62 MPa, reaching 15 % increase. The same trend was observed in flexural strength results, where for CLB, CB1, CCLB and CCB1 after 28 days it was 5.5 MPa, 6.7 MPa, 6.9 MPa and 7.6 MPa, respectively. In the production of low strength concrete specimens CLA, CA1 and CA2 aggregates LA, A1 and A3 were used. All specimens showed similar results in compressive strength after 28 days ranging from 20 to 24 MPa, and in flexural strength ranging from 4 to 5 MPa (Fig. 6 and 7). There is no significant difference between mechanical properties of 3 and 28 days old specimens.

Thermal conductivity of low strength lightweight concrete specimens

The thermal conductivity of 30 × 30 × 5 cm thick plate specimens was measured using a heat flow meter

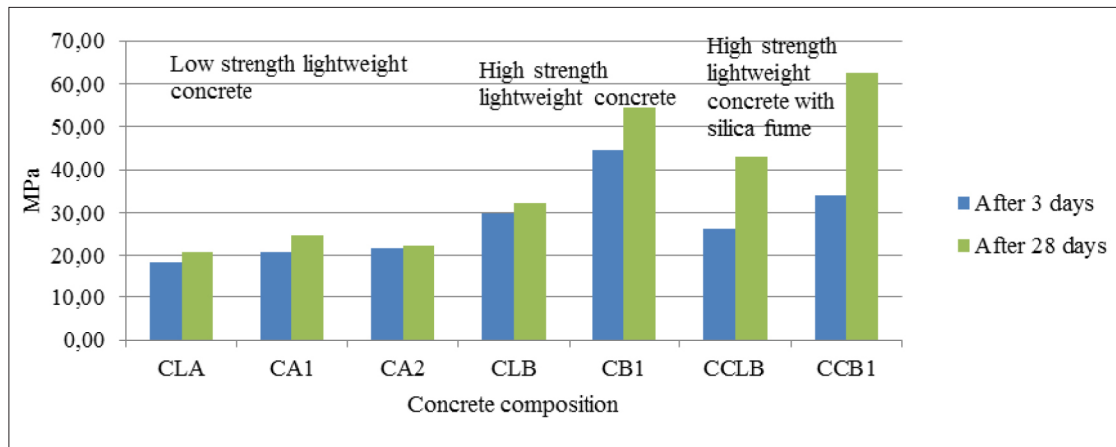


Fig. 7. Compressive strength of lightweight concrete

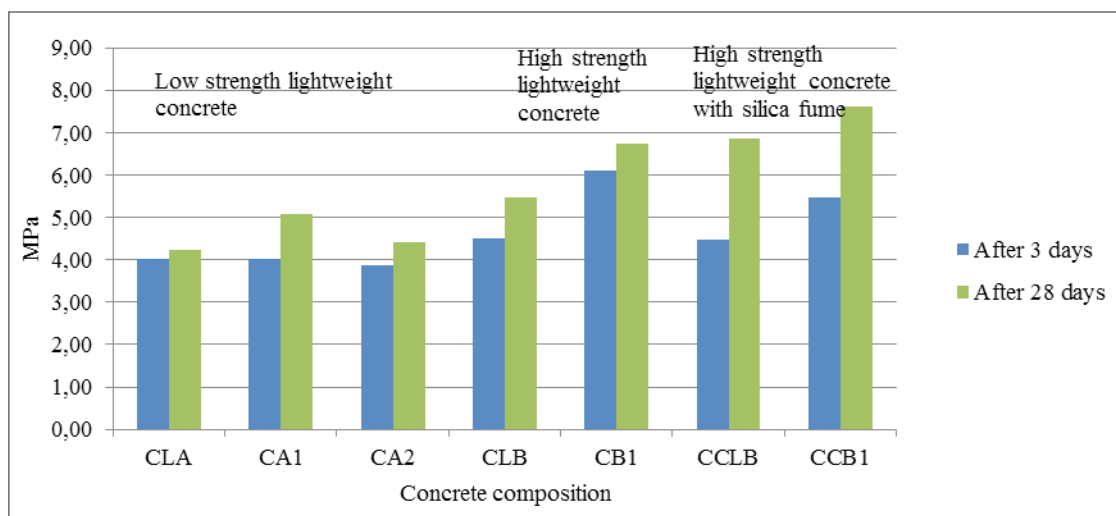


Fig. 8. Flexural strength of lightweight concrete

(LaserComp® Fox 600). The specimens were tested in air-dry conditions.

Thermal conductivity of the lightweight concrete is shown in Table 8. It is seen that for all concrete CLA, CA1 and CA2 samples the conductivity varies in the range from 0.31 W/mK to 0.33 W/mK.

Table 8. Lightweight concrete thermal conductivity

	Thermal conductivity, W/mK
CLA	0.315
CA1	0.327
CA2	0.311

4. Conclusions

Lightweight aggregate with different density (from 320 kg/m³ to 620 kg/m³) and crushing strength (from 0.8 MPa to 4.2 MPa) can be produced by using laboratory rotary kiln with the identical sintering temperature of 1180°C and regime, but changing NMP amount in composition of

raw materials. They can substitute commercially available lightweight aggregates in low and high strength lightweight concrete.

Laboratory sintered aggregates LA and LB are with significantly lower water absorption up to 12% compared with the commercially available aggregates A1 and A2 (~18%). The water absorption for laboratory sintered aggregates is equivalent to high strength aggregates B1 (~12%).

Obtained concrete bulk densities ranged from 1600 kg/m³ to 2020 kg/m³. Hardened concrete bulk density for CLA, CA1 and CA2 was from 1550 kg/m³ to 1600 kg/m³, therefore it was declared as lightweight concrete. High strength lightweight concrete CLB, CB1 and CCLB samples showed bulk density under 2000 kg/m³, but concrete composition CCB1 showed result 2020 kg/m³.

Concrete made with lightweight aggregates with lower crushing strength and bulk density showed lower mechanical properties. Low strength lightweight concrete specimens CLA, CA1 and CA2 showed similar results in compressive strength after 28 days ranging from 20 to 24 MPa, and in

flexural strength ranging from 4 to 5 MPa. Compressive strength of high strength lightweight concrete CLB and CB1 were 32 and 54 MPa after 28 days, and flexural strength were 5.5 and 6.7 MPa, respectively. Additional SF and admixture improved the mechanical properties of CCLB and CCB1, where compressive strength after 28 days were 43 and 62 MPa, and in flexural strength 6.9 and 7.6 MPa.

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References

- Babu K. G., Babu D.S., *Cement and Concrete Composites* 26; 2004, 605 p.
- Bajare D., Korjakins A., Kazjonovs J., Rozenstrauha I. Pore structure of lightweight clay aggregate incorporate with non-metallic products coming from aluminium scrap recycling industry. *Journal of the European Ceramic Society* 32 2012, 141–148 p.
- González-Corrochano B., Alonso-Azcárate J., Rodas M., Barrenechea J. F., Luque F. J. Microstructure and mineralogy of lightweight aggregates produced from mining and industrial wastes. *Construction and Building Materials* 25 2011, 3591–3602 p.
- Lo. Tommy Y., Tang W. C., Cui H. Z. The effects of aggregate properties on lightweight concrete. *Building and Environment* 42 2007, 3025–3029 p.
- Lucheva B, Tsonev T, Petkov R. Non-waste aluminium dross recycling. *Journal of the University of Chemical Technology and Metallurgy* 2005;40(4):335–8.
- Mehta P. K., Monteiro P. J. M. *Concrete, microstructure, properties and materials*. New York: McGraw-Hill Companies; 2006.
- Naik T. R., Moricioni G. *Environmental-friendly durable concrete made with recycled materials for sustainable concrete construction*. Milwaukee, 2006, 13 p.
- Owens, P. L. 1993. *Lightweight aggregates for structural concrete*. *Structural Lightweight Aggregate Concrete*, 1–18.
- Pinto S., Rosenbom K., Machado V. M., Labrincha J. A., Ferreira V. M. Incorporation of sludge in light expanded clay aggregates. *Key Engineering Materials*, 2004, 1391–1394 p.
- Samuel M. A new technique for recycling aluminium scrap. *Journal of Materials Processing Technology* 2003; 135(1):117–24. [http://dx.doi.org/10.1016/S0924-0136\(02\)01133-0](http://dx.doi.org/10.1016/S0924-0136(02)01133-0)
- Shen H, Forssberg E. An overview of recovery of metals from slags. *Waste Management* 2003; 23:933–49 p.
- Shinzato MC, Hypolito R. Solid waste from aluminium recycling process: characterization and reuse of its economically valuable constituents. *Waste Management* 2005; 25:37–46. <http://dx.doi.org/10.1016/j.wasman.2004.08.005>
- Short A., Kinniburgh W. *Lightweight concrete*. 3rd ed. London: Applied Science Publishers; 1978, 321 p.

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