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THE EFFECT OF CONCRETE COMPOSITION AND AGGREGATES PROPERTIES ON PERFORMANCE OF CONCRETE

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Abstract. The properties of the hardened concrete depend on the selected raw materials: size and amount of the particles of coarse aggregate, as well as on the ratio of other components. Particular countries use various methodologies for the selection of concrete composition to select the components of the concrete mixture. However, the properties of the concrete, selected by using any methodology for the selection of the concrete composition and hardened by following the defined conditions, must satisfy the values of certain necessary characteristics. The results of the implemented research indicate that the most optimal solution is to use the coarse aggregate of multi-fractional or discontinuous fractional composition. The optimal composition of the concrete must be selected to ensure that the binding material is not overdosed. Yet, all components must be selected in such a way, that the required properties of the final product are retained after concrete mixture hardens. When catalyst waste materials from the reactor of the catalytic cracking (15%) are used for the lightweight concrete, the density of the expanded–clay lightweight concrete investigated and compressive strength increases even for the higher water/cement ratio, more heat is dissipated during the hydration of the cement and this exothermic effect occurs several hours earlier.

Keywords: concrete, aggregate, expanded–clay aggregate, structural parameters, catalyst, exothermic temperature.

1. Introduction

Concrete production technology is developed rapidly, and concrete's strength is going to reach its limits. Many scientists from all around the world are trying to improve the physical and mechanical properties of the concrete. However, there is a lack of generalised data, predictable dependencies that could be used during the prediction of the physical and mechanical properties of the concrete, when its composition and structure is known.

Gumuliauskas, Skripkiūnas (2007) after the analysis of the over mortared concrete mix, have confirmed that this type concrete, in most cases, has better properties over the normal concrete: this type is more technological, and all properties of this type of concrete are similar or better. In addition, the over-mortared concrete mix is more economical due to its composition, which allows us to save the coarse aggregates without overdosing the cement.

Brouwers *et al.* (2005) have used the three-fraction sand for the concrete production. The provided research data indicate that the mixture, where the fine sand (fraction of 0–1 mm) was used, reached the maximal compressive and bending strength.

Tommy *et al.* (2007) investigated the expanded-clay lightweight concrete, where coarse 5, 15 and 25 mm fraction aggregates were used. The research showed that the samples reached the maximal compressive strength after 28 days of the hardening when with the 15 mm fraction expanded clay. These scientists have stated that the strength of the concrete with the light-weight aggregate depends on the strength of the utilised light-weight aggregates and on the hardened cement paste. The cylinder strength of the aggregates used for the research was equal to 4.27, 5.79 and 1.69 MPa. Pioro, L., Pioro, I. (2004) after an analysis of the expanded clay, have estimated that the cylinder strength of the expanded clay, used for the research, may vary from 0.78 MPa to 14.4 MPa.

Bing *et al.* (2004) have investigated a high-strength concrete, where the coarse aggregates – crushed limestone of 10, 15 and 20 mm size were used. The investigations showed that the maximal compressive strength of concrete is achieved when 10–16 mm fraction aggregates are used and, vice versa, the compressive strength is lowest, when 16–20 mm fraction aggregates are used.

Currently there are intensive investigations carried out in order to utilise the technogenical, constructional, as well as domestic waste for concrete mixtures. The grained rubber of the tyres (Skripkiūnas *et al.* 2007), crushed ceramic bricks (Bektas *et al.* 2008; Cachim 2009), remains of the glass (Zainab *et al.* 2008), plastic waste (Zainab *et al.* 2008), air-entrainment admixture (Szwabowski, Lazniewska-Piekarczyk (2009) and colliery spoil (Kinuthia *et al.* 2009) is utilised to produce concrete mixtures.

Petrella *et al.* (2007) have investigated concrete, where the remains of the glass, gravel and expanded clay were utilised as aggregates. Two concrete mixtures had reached the compressive strength of 20 MPa and 35 MPa

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(the crushed 0.5–2 mm size glass and 2–16 mm fraction gravel was utilised; 0.5–2 mm size expanded clay and 2–16 mm size gravel). The lowest values of the compressive strength were achieved only when the crushed 2–16 mm size glass and expanded clay together with the glass were utilised.

Deltuva, Rudžionis (1997) have estimated that by adding up to 10% of the inert filler aggregate, the density of the hardened cement paste increases up to 4.5% and strength increases up to 40.2% in all cases. After adding 10% of the chemically active filler aggregates (waste of the ferrosilicon), the density of the hardened cement paste increases up to 7.4%, and the strength increases up to 54.7%. After adding 15–20% of the hardened cement paste with the ferrosilicon waste aggregates the strength matches the strength of the cement with no aggregates.

Farid *et al.* 2008 have used the crushed ceramic bricks to replace the fine, as well as the coarse aggregates of the concrete. The crushed ceramic bricks were used to replace 25, 50, 75 and 100% of the concrete aggregates. Investigation results showed that the properties of the concrete product, where 25–50% crushed ceramic bricks are utilised, are similar to the product where no waste aggregates are used.

Paya *et al*. (2001) have proved that the concrete mixture, where water/cement ratio is equal to 0.4 and the plasticizer is not utilised, by additionally adding 15% of the remains of the liquid catalytic cracking, the values of the compressive strength of the hardened samples become lower, comparing to the compressive strength of the reference samples) have used the limestone. The binder was prepared by substitution of cement by limestone filler. Fillers were chosen of various particle sizes and with percentages from 5 to 40. Test results revealed that the replacement of Portland cement by the finest filler of limestone slightly decreases the consistency and the setting times. It is concluded that an addition of finely ground limestone filler only up to 15% gives a better strength.

In recent years the research on the secondary usage of the catalyst waste is carried out widely. Lithuanian oil refinery company Plc "Mažeikiu nafta" utilises more than 40 various type catalysts during the production. According to the manufacturer's information, the catalyst is a scentless composite material (powder form) utilised in the reactor of catalytic cracking.

The results of the research implemented by the Pacewska *et al*. (2002), Jung-Hsiu *et al*. (2003) show, that when catalyst waste materials from the reactor of the catalytic cracking are used for the mixtures of the normal concrete, the compressive strength, density, frost resistance increase and water absorption decreases.

However, it was not possible to find any reference data concerning the results of the research about the usage of this waste material for the mixtures of the expanded-clay lightweight concrete. This waste material, utilised catalyst, belongs to the group of the filler aggregates. The filler aggregates are used for two purposes: to save binding materials, to improve the strength and some other technical characteristics of the products. The binding materials are saved when the cement is mixed with the filler aggregates of the same size. After adding the filler aggregates, the volume of the cement paste increases, the concrete mixture becomes more instable and smoother. When the fine filler aggregate is utilised, its particles fill the hollows created by the cement particles, this increases the density as well as the strength of the hardened cement paste.

The goal of this research is to estimate the variation of the properties of the normal concrete, depending on the selected fractions of the coarse aggregate and methods for selecting the concrete composition, as well as to compare the properties of the expanded-clay lightweight concrete when typical materials and additional waste materials of the catalyst are used in the mixture.

2. Compositions, raw materials and investigation methodologies of mixtures analysed

The following main raw materials were used for the concrete production:

Cement: Portland-composite cement CEM II/A-L 42.5 N, satisfying the requirements of the standard LST EN 197-1:2000.

Fine aggregates: natural sand with the maximal size of the particles not larger than 5 mm. The characteristics of the sand are provided in Table 1.

Coarse aggregates: crushed gravel with the maximal size of 40 mm. The characteristics of the coarse aggregate – gravel are provided in Table 2. The characteristics of the expanded clay sand and expanded clay gravel are provided in Table 3.

Table 1. Characteristics of the fine aggregate

Concrete marking	Sand			
	bulk density, g/cm³	particle density, g/cm³	bulk porosity, %	fineness modulus
A	1.62	2.00	19.0	2.22
B	1.61	1.82	11.6	2.07

During the research 4 concrete mixtures with the markings A, B, C and D were prepared.

Concrete A: class C25/30, slumping factor 3 cm, water/concrete ratio – 0.43. The coarse aggregates with the particles of the following fineness were used for the production of the concrete A: single-fraction gravel 20/40 mm (marking A-1); multi-fractional gravel 5/40 mm (marking A-2); mixture of the two-fraction gravel 5/10 and 20/40 mm (marking A-3).

Table 2. Characteristics of the coarse aggregate

Concrete marking	Gravel			
	bulk density, g/cm³	particle density, g/cm³	bulk porosity, %	cleavage, %
A-1	1.40	2.56	43.43	15
A-2	1.50	2.39	39.40	10
A-3	1.52	2.40	38.59	14
B	1.35	2.60	48.00	14

Concrete B: class C16/20, slumping factor 3 cm, water/cement ratios (0.66; 0.68; 0.68 and 0.58).

The mixture of the concrete B was selected in accordance to the following:

1. computational – experimental method (marking B-1) (Manual for the selection of the dense concrete mixtures NIIZB 1979);
2. tables, diagrams and nomograms (marking B-2) (Manual for the selection of the dense concrete mixtures NIIZB 1979);
3. method used in the USA, called weight method (marking B-3) (Kumar *et al.* 1993);
4. method used in Spain, called the method of *Carlos de la Pena* (marking B-4) (Association national de fabricantes con sellocietan 1991).

The lightweight aggregate – expanded clay was used for the concrete C and D. The following materials were used during mixing the concrete C: expanded clay sand of 0–4 mm fraction, expanded clay gravel of 4–10 mm fraction. The composition of the expanded-clay lightweight concrete C and D was selected by using computational – experimental method described in the reference material (Скрамтаев и др. 1966). Concretes C and D – class C16/20, slumping factor 3 cm, concrete C – water/cement ratio 0.52, and concrete D – water/cement ratio is equal to 0.61. Additionally, 15% of the used catalyst (comparing to the amount of the binding materials) from the reactor of the catalytic cracking is added to the expanded-clay lightweight concrete D.

The chemical composition of the unground catalyst is provided in Table 4. Filler aggregate: the unground catalyst waste materials mostly consist of the silicon and aluminium oxides. Additionally, the remains of the following materials existed in the catalyst: CaO, MgO, K_2O and Na_2O.

Table 3. Characteristics of the expanded clay sand and expanded clay gravel

Fraction of the expanded clay	Properties		
	bulk density, g/cm³	particle density, g/cm³	bulk porosity, %
0–4 mm	0.543	1.5	63.80
4–10 mm	0.428	1.5	71.47

Table 4. Chemical composition of the catalyst waste material

Chemical composition, %					
SiO_2	Al_2O_3	Fe_2O_3	TiO_2	P_2O_5	La_2O_3
55.15	40.94	0.90	1.48	0.11	1.41

The compositions of the concrete mixtures A and B are provided in Table 5. The quantities of the water and cement in the concrete A were equal, only amounts of sand and gravel differed. After the calculation of the composition of the concrete B by using methods I and II it was estimated that the amounts of the raw materials do not differ a lot. However, the mixture, created in accordance to the method III, included significantly larger amount of sand, and the mixture, created in accordance with the IV method, included more cement, gravel and water.

Table 5. Composition of concrete mixtures A and B

Mixture marking	Composition			
	Cement, kg/m³	Sand, kg/m³	Gravel, kg/m³	Water, l/m³
A-1	435	402	1168	187
A-2	435	325	1263	187
A-3	435	321	1268	187
B-1	272	532	1151	174
B-2	292	514	1131	185
B-3	262	966	1015	172
B-4	390	363	1275	221

The concrete D of the concrete mixtures C and D, which compositions are provided in Table 6, differs from the concrete C because the catalyst from the reactor of the catalytic cracking was included additionally.

Table 6. Composition of concrete mixtures C and D

Concrete marking	Composition					
	Cement, kg/m³	Expanded clay, kg/m³		Sand, kg/m³	Water l/m³	Catalyst kg/m³
		0–4 mm	4–10 mm			
C	418	159	238	823	216	–
D	355	159	238	823	216	63

All concrete mixtures were mixed manually in a laboratory. The 10×10×10 cm and 15×15×15 cm dimension samples were formed following the verification and adjustment of the slumping factor of the concrete mixture. The concrete composition was adjusted depending on the moisture content in the aggregates. The created concrete mixture of the required consistence was poured into the moulds smeared with the lubricant. The samples were thickened by vibrating them on the laboratory vibrating plate for approximately 1 min. The samples were stored in the moulds for 19 hours, protected against the shakes, vibrations and overdrying in the environment of the temperature of 20ºC ± 5ºC. After the samples were taken from the moulds, they were immediately immersed into the water with temperature of 20ºC ± 2ºC (LST EN 12390-2 2003). In these conditions the samples were stored until the test for the evaluation of the mechanical properties was carried out. The average compressive strength of the concrete samples produced from the mixtures A and B was estimated after 28 days. The compressive strength of the expanded-clay lightweight concrete C and D was estimated after 2, 7, 14 and 28 days of the hardening. The average values of the analysed characteristics were estimated by using results obtained from 5 samples.

The main physical and mechanical properties of the samples were estimated by using the known standard methodologies: the density of the samples was estimated according to LST EN 12390-7, the compressive strength – LST EN 12390-3.

The thermographic analysis of the exothermic effect were carried out for the concrete mixtures C and D. The temperature variations during the bonding and hardening of the concrete were estimated according to the methodology (Calcium aluminate cements 1999) developed by the company "Alcoa". The analysis was carried out at the room temperature (20±1) °C. 1.3 kg weight paste of the expanded-clay lightweight concrete was poured into the 10×10×10 cm size mould. During the moulding the T type thermocouple, placed in the glass tube, was inserted into the sample. After the formation of the concrete sample, the mould was immediately placed into the metal box and isolated with 50 mm thickness expanded polystyrene cover. The temperature was measured and its values were recorded continuously throughout the heat propagation processes in the sample.

During the test, the exothermic effect was recorded in two different samples: in the first expanded-clay lightweight concrete C and in the second expanded-clay lightweight concrete D, which includes 15% of the used catalyst waste material.

3. Structural parameters

Theoretically, according to the Lykov (Лыков 1978), the simplest model of the porous body can be represented by the system consisting of spherical particles with the small radius and of identical size as well as pores between these particles. The spherical particles may be distributed in the space differently. The low density distribution (cubic ν = 90°) and larger density distribution (hexagonal ν = 60°) are distinguished. The space porosity, in case of the analysed distributions of the particles, depends on the angle ν (an angle between the particles of the material), but not on the radius of the particles. When the distribution of the particles is cubicle, the porosity is 47.64%, when hexagonal – 25.95%. The shape of the pores between the particles can be tetrahedral or rhombohedral. When particles are distributed cubically, the radius of the pores between the particles is equal to 0.41 R. The radius of the larger pores is equal to 0.288 R, in case the shape of the pore is tetrahedral, and 0.414 R, when the shape of the pores is rhombohedral. The tetrahedral pores occupy 7.37% of the volume, and rhombohedral – 18.58%. The structure of the pore volume is characterised according to the homogeneity, anisotropicity and heterogenicity.

The structural factors of the concrete samples, i.e. factor of the directional irregularity of the structure N, capillary speed g of the mass flow rate at the normal conditions, effective porosity W_E, total open porosity W_R and reserve of pore volume R, were estimated by following the methodology described in the reference material (Mačiulaitis 1996; Mačiulaitis *et al.* 2008). The methodology for the estimation of the factors is provided in Table 7.

Table 7. Characteristics of the modified structural factors (Mačiulaitis, Malaiškienė 2009)

Title of the parameter and units of measurement	Physical meaning of the factors	Equations	Description and dimensions of the constituents of the main parameter
Reserve of pore volume R, %	The reserve of pore volume determines the sample's pore volume part that initially is not filled with the water, but is filled gradually during the cyclic tests. Then the force impulse occurs in this part (on the freezing surface). The larger the reserve of pore volume, the higher the volumetric and operational frost resistance of the body shall be	$R = (1 - \frac{W_E}{W_R}) \cdot 100$	W_E – effective porosity according to the water absorption after 72 hours, % W_R – total open porosity according to the water absorption by vacuuming (by using special mode), %
Structure's directional irregularity factor, N	Structure's directional irregularity factor allows us to estimate the irregularity of the structure of the effective capillaries according to their reciprocal length and this factor has an impact on the operational frost resistance	$N = \frac{H_{max} - H_{min}}{H_{min}}$	H_{max}, H_{min} – rates of capillary wetting front (after 2 hours), mm
Effective porosity W_E, %	Sample's effective porosity shows the percentage of the effectively functioning pores and capillaries in the sample.	$W_E = \frac{m_1 - m}{m} \cdot \rho \cdot 100$	m_1 – mass of the sample saturated by using capillary pulling method, g m – mass of the sample dried to the stable mass, g
Capillary rate of mass flow G, g/cm^2	The capillary rate of the mass flow shows the conditional diameter of the effective pores and capillaries.	$G = \frac{m_1 - m}{S}$	m_1 – mass of the sample saturated by using capillary pulling method, g m – mass of the sample dried to the stable mass, g S – area of the sample's effective surface, cm^2
Total open porosity W_R, %	The ratio of the total open porosity characterises sample's all linked open pore volume according to the aspect of macrostructure and microstructure.	$W_R = \frac{m_2 - m}{m} \cdot \rho \cdot 100$	m_2 – mass in the air of the sample impregnated in the vacuum, g m – mass of the sample dried to the stable mass, g ρ – sample's density, kg/m^3

Table 8. Average values of the structural factors of the concrete samples, produced from the mixture A

Marking	Effective porosity W_E, %	Total open porosity W_R, %	Reserve of pore volume R, %
A-1	15.89	18.53	14.30
A-2	20.31	21.64	6.00
A-3	22.80	25.26	10.15

Factors of the normal concrete are provided in Table 8. When the size of the particles of the coarse aggregate is 20/40 mm, the obtained porosity is 18.53%, when 5/40 mm – 21.64%, and when the 5/10 and 20/40 mm size particles were utilised together – 25.26%. Considering the estimated porosity values it can be concluded that the distribution of the particles in the mixtures analysed is hexagonal, because their porosity does not exceed 25.95%. Additionally, by considering the reserve of pore volume, we are able to predict that samples A-1 will have higher volumetric and operational frost resistance, and samples A-2 will have lower volumetric and operational frost resistance.

Numeric values of the structural factors, provided in Table 9, show that highest water absorption after 72 hours of soaking is obtained in the samples produced from the mixture A-2, where multi-fractional 5/40 mm size aggregates were utilised. The anisotropy factors of the structure's directional irregularity in the concrete samples A-1 and A-2 are very similar. And this factor in the sample A-3, where two-fraction gravel mixture of 5/10 and 20/40 mm size was utilised, is slightly lower. Structure's directional irregularity factor of the samples, which composition was selected according to the computational-experimental method, is the highest, and samples of the concrete B-2 have the lowest value of this factor. Considering the factors of the capillary mass flow rate, we can predict that conditional diameter of the effective pores and capillaries would be higher for the samples A and vice versa.

Table 9. Average water absorption, structure's directional irregularity factor and capillary rate of mass flow values of the concrete samples

Marking	Water absorption, W, %	Structure's directional irregularity factor, N	Capillary rate of mass flow G, g/cm^2
A-1	7.14	1.12	0.50
A-2	8.25	1.15	0.48
A-3	7.87	0.88	0.49
B-1	3.63	0.79	0.29
B-2	3.86	0.40	0.37
B-3	4.04	0.53	0.31
B-4	4.03	0.43	0.34

4. Experimental results

Average compressive strength and density values of all samples after 28 days of the hardening are provided in Table 10.

Table 10. Average density and compressive strength values of the concrete produced from the mixtures A, B, C and D

Mixture's marking	Average density, kg/m³	Average compressive strength after 28 days, MPa
A-1	2185	27.17
A-2	2191	32.95
A-3	2222	33.32
B-1	2390	21.66
B-2	2345	17.78
B-3	2282	18.38
B-4	2411	22.80
C	1526	16.69
D	1643	20.74

Research results show that the highest density of the samples, which were produced by utilising the mixture of two-fraction gravel (5/10 and 20/40 mm), is 2222 kg/m³, however, the highest compressive strength is achieved for the samples where multi-fractional 5/40 mm gravel was utilised. The highest values of the properties of the concrete samples produced from the mixture B were obtained by estimating the composition of the mixtures, according to the method I and IV. The lowest density and compressive strength of the samples is obtained by calculating the concrete composition, according to the data from the tables, diagrams, nomograms and the method used in the USA, called as a weight method.

Deltuva (2001) has stated in his research, that the strength of the concrete can be ensured in several ways: by changing the composition of the mixture, especially the water/cement ratio, granulometric composition of the aggregates and by implementing particular technological measures. During our implemented research the class of the concrete A was selected as C25/30, but results of the experiment show that the compressive strength of the concrete meet the defined requirements for the strength, when multi-fractional 5/40 mm size gravel and two-fraction mixtures of 5/10 and 20/40 mm size are utilised, but the compressive strength of the mixture A-1 has not reached the required value. The concrete samples produced from the mixtures B-1 and B-4 satisfy the requirements of the concrete of the intended class, but the samples produced from the mixtures B-2 and B-3 do not. The density of the concrete A and B satisfy the density requirements for the normal concrete.

The density of the expanded-clay lightweight concrete samples produced from the mixtures C and D differs slightly, it has increased by 7.7%. However, the compressive strength is higher in the samples which have the catalyst waste material additionally included in the mixture.

The average compressive strength values of the concrete samples C and D, estimated after 2, 7, 14 and 28 days of the hardening, are shown in Fig. 1.

As it can be seen from Fig. 1, the compressive strengths of the concrete C and D differ. The strengths of the concrete are similar after 2 days, but the difference increases considerably after 14 and 28 days. The similar results were obtained in our earlier investigations (Vaičienė 2007). Considering the results of the investigation, we can conclude that, comparing to the strength after 7 days, the strength of the expanded-clay lightweight concrete has increased gradually, after 14 days the compressive strength of the concrete C and D has increased by 14.78%, and by 24.27% after 28 days.

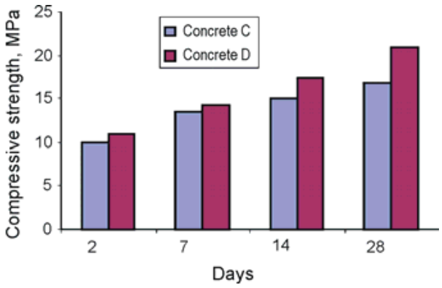

Fig. 1. Average compressive strengths of the concrete C and D

Fig. 2 and 3 show the views of the concrete samples after the application of the compression press. Fig. 2 shows the view of the compressed sample, which was hardened for 2 days and produced from the mixture C of the expanded-clay lightweight concrete. Fig. 3 shows the view of the compressed sample, which was hardened for 2 days and produced from the mixture D. In the figures it can be seen that the compressed samples have different colours. The hardened cement paste of the samples, where the catalyst was utilised in the mixture, is much lighter and less destroyed granules of the expanded clay can be seen.

Fig. 2. View of the sample, produced from the mixture C, after compression test

Fig. 3. View of the sample, produced from the mixture D, after compression test

From Fig. 2 it can be stated, the strength of the hardened cement paste after 2 days of the hardening is higher than the one of the expanded clay granules and fragmentation occurs in the granules of the expanded clay. Skripkiūnas, Vaitkevičius (2001) have identified that the fragmentation of the concrete with the porous coarse expanded clay occurs in the particles of the aggregate, but not in the contact area between the mortar and aggregate as this happens during the testing of the concrete with the high density coarse aggregate.

Fig. 3 shows that fragmentation occurs not in the granules of the expanded clay, but the cement paste cracks first during the compression. The adhesion of the cement paste in the sample after 2 days of the hardening is lower than the strength of the expanded clay granules.

During the hydration of the cement, considerable large amounts of the heat are dissipated in the cement paste. These amounts of the heat are different during the various stages of the hydration of the cement (Тейлор 1996). During the measurement of the exothermic effects the influence of the catalyst waste material during the hardening of the mixture of the expanded–clay lightweight concrete was estimated. Fig. 4 shows that during the hydration the temperature of the mixture of expanded–clay lightweight concrete reached 27 °C, when used catalyst was not included (mixture C), and temperature has reached 27.6 °C, when catalyst waste material was used (mixture D). The sample with the catalyst has reached the maximal exothermic temperature earlier, after 880 minutes, and after 1179 minutes, when waste material was not utilised. The results of the analysis showed that the larger the water/cement ratio, the shorter the induction period of the hydration of the Portland cement and the sooner the maximal exothermic temperature is reached. After reaching the maximal value the exothermic temperature decreases.

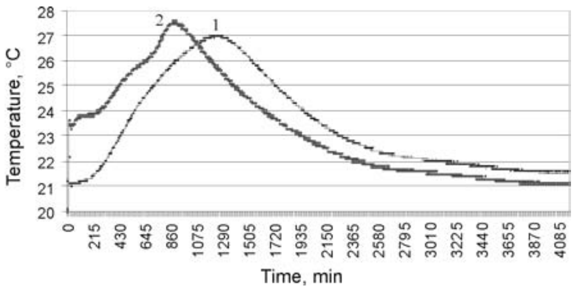

Fig. 4. The temperatures of the exothermic effect of the expanded-clay lightweight concrete during the hardening

Note: 1 – expanded-clay lightweight concrete without the waste material, when water/concrete ratio is 0.52; 2 – expanded-clay lightweight concrete with 15% of waste material, water/cement ratio is 0.61

Radiographic analysis was carried out for the samples produced from the concrete mixtures C and D. According to the data of the X-ray pattern shown in Fig. 5, it was estimated that the main minerals of the expanded-clay lightweight concrete produced from the mixture C are ettringite, dolomite, silica, calcite, portlandite, sunstone and cement minerals. Mituzas *et al.* (2001) have identified that the hydrated cement minerals (for instance, ettringite) growing in the cracks reduce the strength of the hardened cement paste over the time.

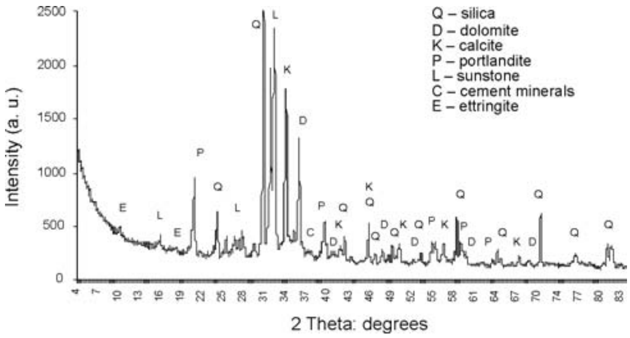

Fig. 5. X–ray patterns (nm) of the concrete sample produced from the mixture C

Considering the data of the X-ray pattern, shown in Fig. 6, it was identified that the main minerals of the samples of the expanded-clay lightweight concrete, where 15% catalyst waste materials were utilised (D), are illite, silica, calcite, portlandite, sunstone and cement minerals. Therefore, due to the formation of the ettringite in the mixture C, comparing to the D composition, where ettringite does not exist, it can be explained, why the values of the mechanical properties of the samples C are lower comparing to the ones of D.

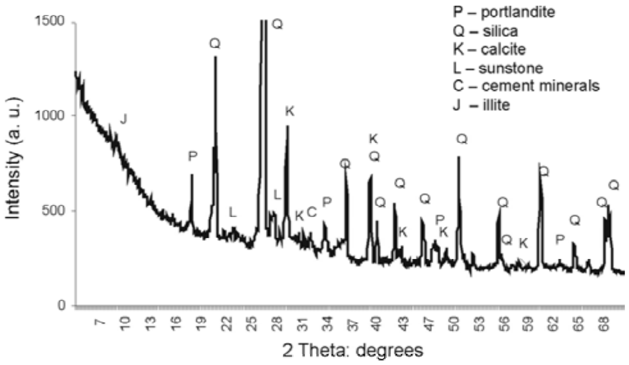

Fig. 6. X-ray pattern of the concrete sample produced from the mixture D

5. Conclusions

1. After implementing of the investigations it was identified that the physical and mechanical properties of the hardened normal concrete depend on the size of the utilised coarse aggregates. The samples, where the mixture of two-fraction gravel was utilised for the production, have the largest density comparing to the multi-fractional and single-fraction coarse aggregates. The largest compressive strength – 33.62 MPa is achieved in the samples, where multi-fractional aggregates were utilised.

2. After the analysis of the different selection methods for the concrete it was identified that the maximal strength is achieved, when concrete mixtures are selected in accordance with the computational – experimental and Carlos de la Pena methods'. The former case can be explained by the fact that finer aggregate was utilised for this method, and the latter – considerably larger amount of the cement was utilised.

3. By comparing the structural characteristics of the samples produced from the mixtures analysed, it was identified that the capillary rate of mass flow is lower for the samples B-1. Additionally, considerably less binding material was utilised for the production of these samples, the structure of the mixture became smoother, and the structure's directional irregularity factor of the mixture was larger than 1.

4. The density of the samples of the expanded-clay lightweight concrete, where 15% of catalyst waste material was added from the reactor of the catalytic cracking, has increased by 7.7%, and the compressive strength – by 24.27%. It is possible that such increase of the density and mechanical characteristics has resulted from the fact that no ettringite was formed in the mixture in this case.

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BETONO SUDĖTIES IR UŽPILDŲ SAVYBIŲ ĮTAKA BETONO SAVYBĖMS

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S a n t r a u k a

Sukietėjusio betono savybės priklauso nuo betonui parinktų žaliavų: stambaus užpildo dalelių dydžio ir jų kiekio, taip pat nuo kitų sudedamųjų dalių santykio. Betono mišinio sudedamąsias dalis šalys parenka įvairiais betono sudėties parinkimo metodais, tačiau pagal bet kurį betono sudėties parinkimo metodą parinkto ir pagal nustatytas sąlygas sukietinto betono savybės turi tenkinti tam tikrų būtinųjų charakteristikų vertes. Darbe atliktų tyrimų rezultatai parodė, kad optimaliu naudoti daugiafrakcį arba trūkiosios frakcinės sudėties stambųjį užpildą. Betono sudėtis turi būti parinkta nepereikvojant rišamosios medžiagos, tačiau visas sudedamąsias dalis parenkant taip, kad, sukietėjus betono mišiniui, išliktų reikiamos galutinio produkto savybės. Lengviesiems betonams naudojant katalizatoriaus atlieką iš katalitinio krekingo reaktoriaus (15 %), padidėja tiriamojo keramzitbetonio tankis, gniuždomasis stipris net esant didesniam V/C santykiui, o hidratuojantis cementui, išsiskiria daugiau šilumos, ir šis egzoterminis efektas įvyksta keliomis valandomis anksčiau.

Reikšminiai žodžiai: betonas, užpildai, keramzitas, struktūriniai rodikliai, katalizatorius, egzotermijos temperatūra.

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