*ISSN 1392–1320 MATERIALS SCIENCE (MEDŽIAGOTYRA). Vol. 19, No. 1. 2013*

# The Influence of Crushed Concrete Demolition Waste Aggregates on the Hardening Process of Concrete Mixtures

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http://dx.doi.org/10.5755/j01.ms.19.1.3833

*Received 28 August 2011; accepted 22 June 2012*

Concrete – complex structure composite material consisting of the components with various structure and size. Not only coarse and fine aggregates are used in concrete production, but also filler aggregates. Aggregates of natural, man-made origin or aggregates, produced from recycled materials, can be utilised in concrete production. Aggregates can be produced from recycled materials by reprocessing of concrete and reinforced concrete waste.

The influence of the filler aggregates produced from the crushed concrete waste on the characteristics of binder's paste, when part of the binder (5; 10; 15; 20; 25; 30 %) is replaced by such filler aggregate, is analysed in the research.

Concrete mixtures with natural aggregates and crushed concrete waste were selected and concrete mixtures of required consistence were produced during the research. Exothermic reactions take place during the hardening of concrete mixture, at that time the heat is dissipated, which increases the temperature of the concrete sample. Thus the exothermic processes were investigated during the concrete's mixture hardening period and the temperatures of exothermic reactions were determined.

*Keywords*: concrete waste, recycled aggregate, filler aggregate, microstructure, exothermic effect.

## INTRODUCTION

Concrete – complex structure composite material consisting of the components with various structure and size. Not only coarse and fine aggregates are used in concrete production, but also filler aggregates very often are used in concrete production. Aggregates of natural, man-made origin or aggregates formed from recycled materials can be utilised in concrete's production. Aggregates of recycled materials can be produced by reprocessing of construction demolition waste, including catalyst waste [1], concrete and reinforced concrete waste [2, 3], wood waste glass debris. Binder is one of the most expensive raw materials in concrete's production. Therefore there is a search of the ways to replace a part of the binder in cement concrete with other materials. Vaičienė et al. has analysed the replacement of cement with the active additive – catalyst waste from the reactor of catalytic cracking and found that, when 10 % of the cement is replaced by catalyst waste, compressive strength of expanded-clay lightweight concrete decreases by only 8 % [4].

After the measurement of exothermic effects, researchers have analysed the influence of catalyst waste on the hardening of the mixture of expanded-clay lightweight concrete. The obtained results showed that the temperature of mixture of the expanded-clay lightweight concrete without catalyst waste increased up to 27 °C during the hydration process, and temperature increased up to 27.6 °C when catalyst waste was used. In addition, the sample with this waste reached the maximal value of exothermic effect earlier [5].

No comparative research results, showing the changes of hydration thermal characteristics of concrete mixture, when crushed concrete waste is used as filler aggregate, it was possible to find in scientific literature.

This research deals with the possibility to use crushed concrete waste in the normal concrete mixtures. The main objective of this research is to analyse the influence of coarse, fine and filler aggregates, produced from concrete waste, on concrete mixture hydration process.

## MATERIALS

For the research the following raw materials were used in the concrete's production:

Cement: Portland limestone cement CEM II/A-L 42.5 N, satisfying the requirements of standard LST EN 197-1 [6]. Physical-mechanical characteristics of the utilised cement are shown in Table 1.

Chemical composition of the cement is provided in Table 2, mineral – in Table 3.

Coarse aggregate: gravel breakstone and crushed concrete waste with the particles' size from 4 mm to 16 mm.

Fine aggregate: natural sand and crushed concrete waste, which particles' size was smaller than 4 mm, were used as the fine aggregate.

Main characteristics of the coarse and fine aggregate are shown in Table 4.

**Table 1.** Physical-mechanical properties of the cement

| Parameter | Value |
|---|---|
| Size of particles, μm | 5 – 30 |
| Specific particles' density, g/cm$^3$ | 2.75 |
| Bulk density, g/cm$^3$ | 1.02 |
| Specific surface, cm$^2$/g | 3950 |
| Initial set, min | 230 |
| Final set, min | 270 |
| Early compressive strength after 2 days, N/mm$^2$ | 21 |
| Standard compressive strength after 28 days, N/mm$^2$ | 47 |

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**Table 2.** Chemical composition of the cement

| Chemical composition, % | | | | | | |
|---|---|---|---|---|---|---|
| CaO | $SiO_2$ | $SO_3$ | FeO | $Al_2O_3$ | MgO | $K_2O$ |
| 67.81 | 14.67 | 5.72 | 3.57 | 3.33 | 3.07 | 1.83 |

**Table 3.** Mineral composition of the cement

| Mineral composition, % | | | |
|---|---|---|---|
| $C_3S$ | $C_2S$ | $C_3A$ | $C_4AF$ |
| 57.26 | 15.41 | 8.68 | 10.15 |

**Table 4.** Characteristics of the coarse and fine aggregate

| Aggregate | | Parameter and its value | | |
|---|---|---|---|---|
| | | Bulk density, g/cm$^3$ | Particles' density, g/cm$^3$ | Hollowness, % |
| Coarse aggregate 4/16 mm | Crushed gravel | 1.44 | 2.45 | 41 |
| | Concrete waste | 1.27 | 2.30 | 45 |
| Fine aggregate 0.125/4 mm | Sand | 1.64 | 2.41 | 32 |
| | Concrete waste | 1.21 | 2.30 | 47 |

Filler aggregate: crushed concrete waste, which particles' size is smaller than 0.125 mm. Characteristics of the filler aggregate are shown in Table 5.

**Table 5.** Characteristics of the filler aggregate

| Filler aggregate | Parameter and its value | | |
|---|---|---|---|
| | Bulk density, g/cm$^3$ | Particles' density, g/cm$^3$ | Specific suface, cm$^2$/g |
| Crushed concrete waste 0.125/0 mm | 0.95 | 2.50 | 2905 |

## COMPOSITION OF THE MIXTURES

7 concrete compositions – K, C/1, C/2, C/3, C/4, C/5, C/6, C/7 were selected depending on the characteristics of raw materials, by using data from the tables, diagrams and nomograms. Compositions of concrete mixtures and the markings of the compositions are shown in Table 6. The selected class of concrete's compressive strength is C30/37, slumping factor of the mixture – S1, ratio of water and binder W/B – 0.52, only in the mixture C/6 the ratio of W/B is 0.54.

Natural, as well as man-made aggregate, produced during the crushing of concrete waste, was used in the research. The size of the particles of the coarse aggregate was 4/16 mm, fine aggregate – 0.125/4 mm.

Natural coarse and fine aggregates were used in concrete mixtures K and C/2. In other mixtures the breakstone was replaced by the crushed concrete waste.

In mixture C/1 whole amount of coarse and fine aggregates was replaced by concrete waste. Coarse and fine aggregates were produced after the crushing concrete waste with an alligator and by sifting out the produced material into fractions belonging to coarse aggregates, fine aggregates and filler aggregates. Fine aggregate was cleaned from the particles smaller than 0.125 mm.

In compositions C/4 and C/5, the fine aggregate was not cleaned from the particles with the size of 0/0.125 mm.

During the selection of concrete compositions, in C/2 and C/3 mixture, the amount of 15 % of cement was replaced by filler aggregate produced after the sifting out the crushed concrete and reinforced concrete debris into the corresponding fractions.

During the preparation of the concrete mixtures, the fine and coarse aggregates, as well as cement, were proportioned by mass, and water – by volume. Water in the concrete mixture acts as a binding liquid medium, which forms cement stone of the required strength by reacting with minerals of cement [7]. Therefore, the selection of the amount of water for the concrete's mixture is very important stage as it depends on the concrete's composition and characteristics of its components. Minimal amount of water shall be sufficient to produce the concrete's mixture of the required consistence. When a part of the cement is replaced by the filler aggregate, produced from the concrete waste, the required amount of water, necessary to prepare the concrete paste of normal consistence, increases. Therefore, by considering the recommendations of the methodology for the selection of the concrete, the amount of water was increased in the composition C/6.

## RESEARCH METHODOLOGY

During the investigation the mineral composition of the filler aggregate was identified. X-ray diffraction analysis of the filler aggregate was implemented by using diffractometer DRON-2 (Cu anode, Ni filter, monochromator, gaps 1 : 8 : 0.5 mm).

**Table 6.** Composition of concrete mixtures

| Concrete marking | Composition | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Cement, kg/m$^3$ | Coarse aggregate, kg/m$^3$ | | Fine aggregate, kg/m$^3$ | | Filler aggregate, kg/m$^3$ | Water, l/m$^3$ | W/B |
| | | Crushed gravel | Concrete waste | Sand | Concrete waste | | | |
| K | 444 | 537 | – | 764 | – | – | 231 | 0.52 |
| C/1 | 444 | – | 537 | – | 764 | – | 231 | 0.52 |
| C/2 | 377 | 537 | – | 764 | – | 67 | 231 | 0.52 |
| C/3 | 377 | – | 537 | – | 764 | 67 | 231 | 0.52 |
| C/4 | 444 | – | 537 | – | 715 | 50 | 231 | 0.52 |
| C/5 | 444 | – | 537 | – | 665 | 100 | 231 | 0.52 |
| C/6 | 377 | – | 537 | – | 764 | 67 | 241 | 0.54 |

Operation mode of the tube of diffractometer: $U = 30$ kV, $I = 10$ mA. The recorded diffractogram was decoded by comparing the obtained experimental values of interplanar distances d and specific integral intensity I/I0 values of the lines with the corresponding values in ASTM file.

During the research the amount of water, required to achieve the normal consistence of the paste of Portland cement with filler aggregate additive, was identified. The experiment was implemented in accordance with the standard LST EN 196-3:2005+A1:2009 [8]. In addition, the beginning of the binding process of the mixtures with the cement and with 0; 5; 10; 15; 20; 25; 30 % amount of filler aggregate was identified.

During the research the characteristics of exothermic effects, which occur during concrete hardening process, were determined. The temperature variations during the binding and hardening of the concrete were estimated according to the methodology developed by the company "Alcoa" [9]. The analysis was carried out in laboratory conditions at the temperature of 20 °C ±1 °C. The temperature of the concrete components utilised – water, cement, aggregates, was 20 °C ±1 °C. Initially solid components were mixed in dry conditions, then with the required amount of water. After mixing of the components, the mass consistence was poured into (100×100×100) mm size moulds made from the fabric-base laminate. Thermocouples were inserted into the mixture mass. These thermocouples were used to automatically identify temperature increase of the concrete mixture during the hardening process and to send the data to computer equipment.

The microstructure of concrete waste particles was observed by a SEM (EVO LS 25, Zeiss Germany).

## EXPERIMENTAL RESULTS

X-ray diffraction pattern of the filler aggregate, produced from the crushed concrete waste, is provided in Figure 1.

We can notice that the main minerals of this raw material are as follows: quartz Q (0.137, 0.138, 0.145, 0.154, 0.167, 0.182, 0.197, 0.213, 0.223, 0.228, 0.246, 0.335, 0.425 nm), calcite K (0.152, 0.160, 0.18 7, 0.198, 0.209, 0.250, 0.304, 0.385 nm), dolomite D (0.180, 0.201, 0.219, 0.240, 0.269, 0.402 nm), feldspars F (0.319, 0.324 nm), portlandite P $Ca(OH)_2$ (0.491 nm) dominates as well, illite I (0.100 nm). It can noticed, that there a no unhydrated cement minerals. However, there is Portlandite formed that can be considered as a product of the hydration of cement minerals or fragmentation product of cement stone.

Surface view of the particles of the filler aggregate produced from concrete waste is shown in Figure 2. It can be seen that the shape of the powder is irregular, particles have different size and sharp edges. When the view of the filler aggregate produced from concrete waste is compared with the view of particles of Portland cement [10], it can be noticed that the particles of Portland cement and filler aggregate have similar size. In both cases larger and significantly smaller particles exist, and the views of particles' surface are similar - particles have cloven surface and sharp edges. However, higher amount of larger particles, with the size reaching 100 μm, exists in the filler aggregate. On the other hand, in Portland cement the size of larger particles reaches 50 μm – 60 μm. In addition, Portland cement has higher amount of smaller particles reaching 1 μm – 10 μm.

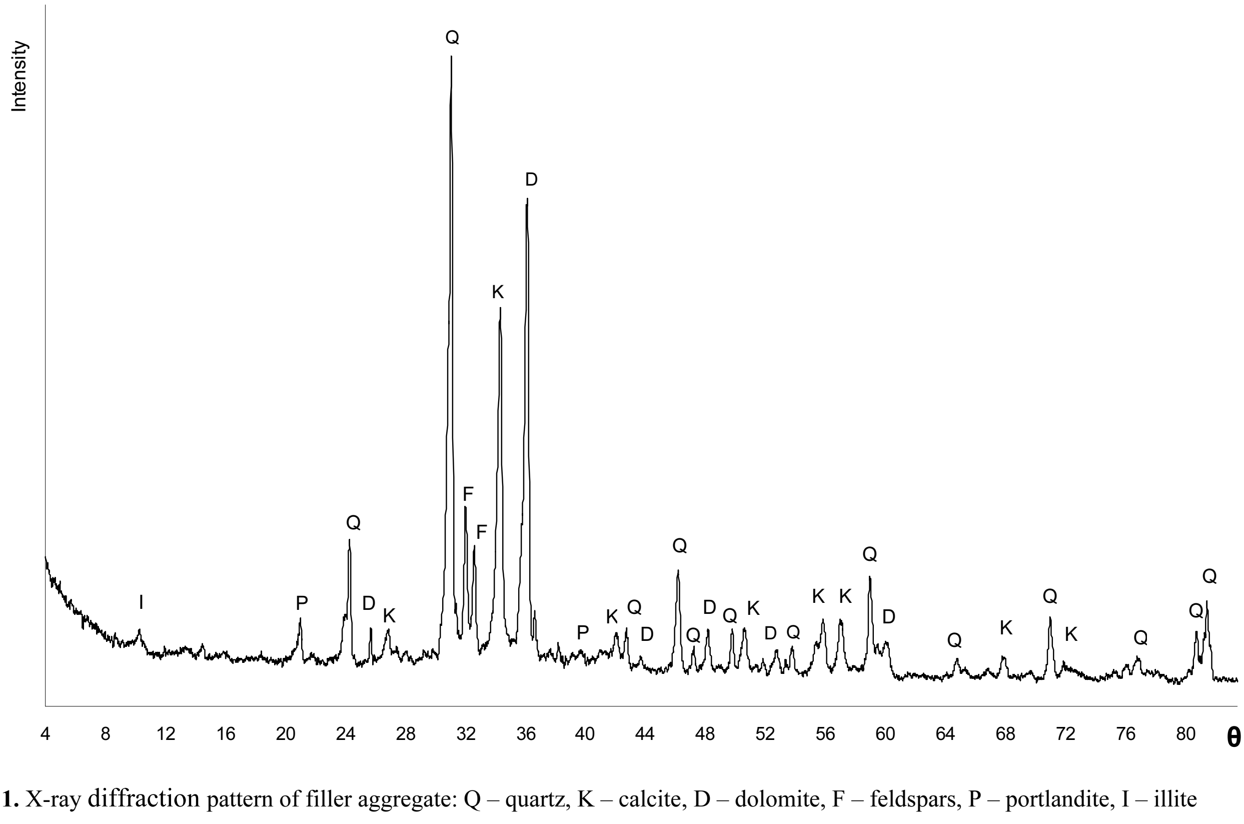

**Fig. 1.** X-ray diffraction pattern of filler aggregate: Q – quartz, K – calcite, D – dolomite, F – feldspars, P – portlandite, I – illite

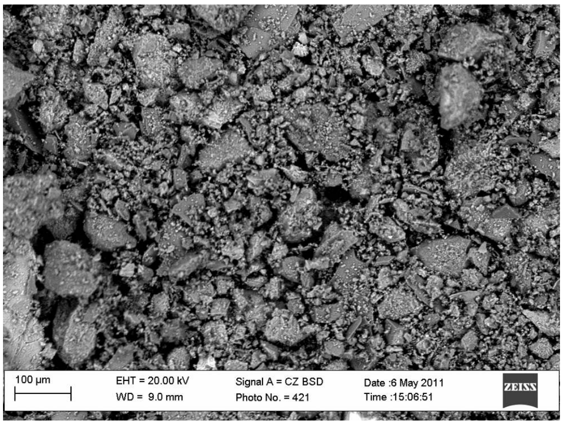

**Fig. 2.** Microstructure of the filler aggregate grains from concrete waste

The investigation of binder's paste (Portland cement and Portland cement + aggregate) of normal substance was implemented. Paste of Portland cement is a mixture of Portland cement and water. Portland cement paste of normal consistence is defined by the percentage of water amount in relation to the mass of Portland cement. 5; 10; 15; 2; 25 and 30 % of the cement mass was replaced by the filler aggregate. Figure 3 shows the relation between water demand and the amount of filler aggregate.

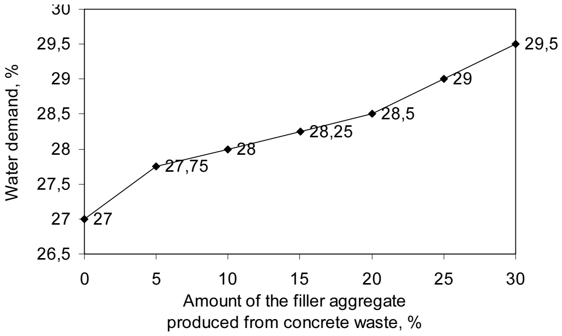

**Fig. 3.** Investigation results of the binder of normal consistence

Investigation results showed that after a part of cement is replaced by the filler aggregate, produced after the crushing of concrete waste, water demand, required to prepare the cement paste of normal consistence, increases. It can be noticed that, when waste material is not used, cement paste of normal consistence can be prepared by using 27 % of water in relation to the mass of Portland cement. After 5  of cement is replaced by the crushed concrete waste with the particles of 0/0.125 mm size, water demand increases up to 27.75 %. When the amount of filler aggregate is increased further, every time by 5 %, water demand increases in steps equal to 0.25 % and 0.5 %.

Initial set was identified through the experiments by applying the standard methodology. Initial set was identified for the Portland cement and Portland cement mixed with 5; 10; 15; 20; 25 and 30 % amount of the filler aggregate, produced from concrete waste. Investigation results are provided in Figure 4.

The initial set of Portland cement CEM II/A-L 42.5 N used for the research was 230 minutes after the paste mixing. When part of the cement is replaced by the filler aggregate, produced during the crushing of concrete and reinforced concrete waste, the time period of initial set increases. Therefore, after 15 % of cement part is replaced by the filler aggregates from concrete waste, initial set of Portland cement was 250 minutes, and, when 30 % of the filler aggregate from concrete waste was added, initial set of Portland cement was 290 minutes.

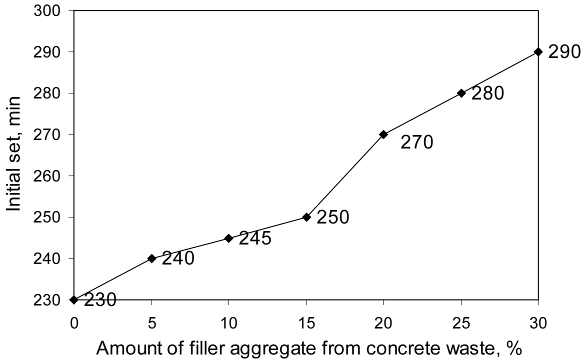

**Fig. 4**. Results of initial set

It can be noticed that, although the particles of the filler aggregate are similar to the ones of Portland cement, the former increase water demand to prepare the normal paste and increase the initial set.

In order to define the influence of the aggregates produced from the concrete demolition waste, on the hardening process of the concrete mixture, the measurements of the characteristics of exothermic effect were carried out. During the hardening process of the concrete mixture the heat is dissipated that increases concrete's temperature. Figure 5 shows the results of thermographic analysis of exothermic effect of the concrete mixture with the natural aggregates. The part of the cement in sample C/2 was replaced by the filler aggregate produced after the crushing and sifting out the concrete waste.

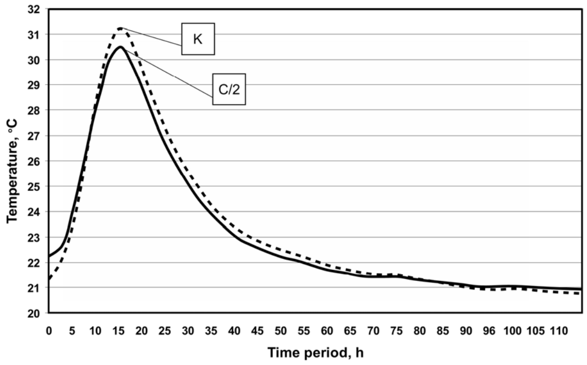

**Fig. 5.** The temperatures of the exothermic effect of the concrete during the hardening process: K – concrete without waste material; C/2 – concrete where 15 % of cement was replaced by waste material; water/binder ratio is 0.52

In the course of thermographic analysis of exothermic effect and during the identification of the temperature values of this effect, the influence of the concrete and reinforced concrete waste on the hardening process of the concrete mixture was investigated. Figure 5 shows that the concrete mixture, where no concrete waste was used during the preparation, reached the temperature of 31.28 °C within 15 hours and 45 minutes. When the amount of cement was reduced and replaced by the filler aggregate produced from concrete waste, the maximal temperature of concrete mixture – 30.51 °C was reached within 15 hours and 35 minutes. The highest value of the temperature of concrete mixture decreased by only 0.77 °C, and the time period, required to reach the highest temperature, become shorter by 10 minutes. A researcher Aleknevičius has analysed the influence of catalyst waste additive of catalytic cracking in oil industry on cement hydration process. It was identified that this additive advances the initial set of cement paste, replaces and advances the formation of crystallohydrates. After the adding of catalyst waste additive to the mixture, the time period, required to reach the maximal temperature of exothermic process, decreases considerably [11]. The scientists have determined that when a part of the cement is replaced by the catalyst waste, temperature of mixture's exothermic effect increases by 0.6 °C, and time period, required to reach this temperature, decreases by 5 hours. In addition, the influence of water and cement ratio W/C on the period of the hydration of Portland cement was investigated. After this investigation it was found that the larger W/C ratio, the shorter inductive hydration period of Portland cement and the earlier the maximal temperature of the exothermic effect is reached [5].

However, if the results of the analysis of exothermic effects of the concrete mixtures, where the amount of cement was not reduced, but only natural aggregates or only the aggregates, produced after crushing of the concrete waste, were used are compared, it can be noticed that both mixtures reached almost the same maximal temperature of exothermic effect. Figure 6 shows concrete's temperature variation curves K and C/1 during the hardening process of the mixtures. Concrete sample (marked as K), which is composed only from natural conventional aggregates, reached 31.28 °C maximal temperature within 15 hours and 45 minutes. Whereas after the natural aggregates are replaced by concrete waste, the maximal temperature of exothermic effect – 31.24 °C of the concrete sample (marked C/1) was reached after 14 hours and 30 minutes.

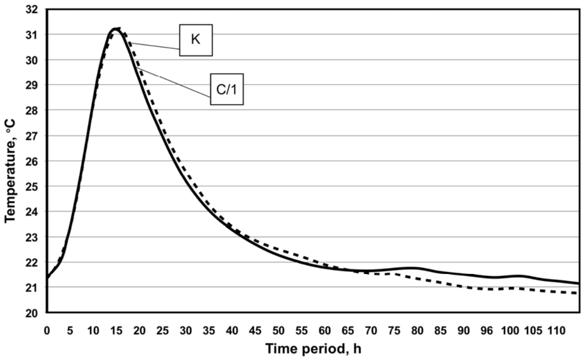

**Fig. 6.** The temperatures of the exothermic effect of the concrete during the hardening process: K – concrete without waste material; C/1 – concrete, with waste material; water/binder ratio is 0.52

Concrete mixtures C/1, C/4 and C/5 had equal amount of cement, but in C/1 mixture coarse and fine aggregates, produced from the concrete waste and separated from fine particles with the size of 0/0.125 mm, were used. In C/4 and C/5 compositions coarse aggregate with particles' size of 4/16 mm was used. Fine aggregate was not separated from the finest particles, therefore sand fraction consisted of the particles with the size of 0/4 mm. Figure 7 shows the thermographic analysis of exothermic effect of the mixtures C/1, C/4 and C/5 during the concrete hardening process.

Coarse aggregates, produced from the concrete waste, are separated from the fine particles during the production process, but the fraction of fine aggregates usually is 0/4 mm, i. e. they are not separated from very fine particles, which size is smaller than 0.125 mm. When such aggregates, which are contaminated with high amount of fine particles, are used, concrete's characteristics worsen. By considering the curves shown in Figure 7, it can be stated, that, when the amount of fine particles (< 0.125 mm) increases, the maximal temperature of the exothermic process decreases and the time period, within which the maximal concrete temperature is reached during the exothermic process, becomes longer. This trend is illustrated by exothermic effects occurring during the hydration of concrete mixtures C/4 and C/5.

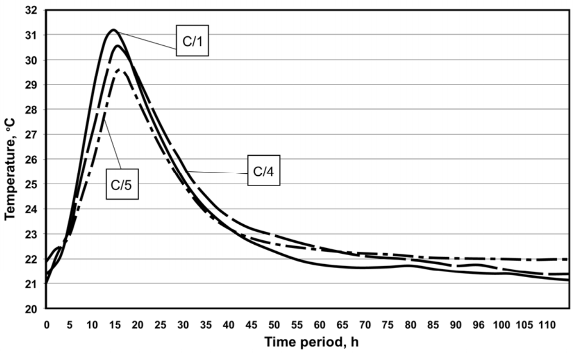

**Fig. 7.** The temperatures of the exothermic effect of the concrete during the hardening: C/1 – concrete, with waste material; C/4 – concrete, with waste material and fine aggregate with 0/0.125 mm particles from crushed concrete waste; C/5 – concrete, with waste material and fine aggregate with double amount of the particles with the size of 0/0.125 mm from crushed concrete waste; water/binder ratio is 0.52

The maximal hydration temperature of the mixtures, which were produced by using 4/16 mm fraction coarse aggregate and 0/4 mm fine aggregate with very fine particles, with the size smaller than 0.125 mm (marked as C/5), can rise up to only 29.62 °C. [12] group of researchers have analysed the exothermic processes of high aluminate cement, slag waste of metallurgy, as well as liquid glass (sodium silicate solution) and their compositions. It was determined that the maximal exothermic temperature of 99 °C of the mixture formed from only the high aluminate cement is reached after approximately 10 hours. After the analysis of the mixture formed from slag waste of metallurgy as well as from the liquid glass, it was found that the temperature of the exothermic effect started to increase exactly after adding the required amount of water, and increased only to 24 °C within 20 minutes. Scientists have also analysed a composition of high aluminate cement, liquid glass and slag waste of metallurgy. The results of the analysis of the reactions of exothermic process show that the maximal temperature of 36 °C of this mixture was reached within 8 hours [12].

During the investigation it was noticed that after a part of the cement is replaced by the filler aggregate, produced after the crushing of concrete waste, the amount of water, required to prepare the cement paste of normal consistence, increases. Water absorption of the aggregates, produced from concrete waste, is higher than the one of natural aggregates. This increase of water demand can be explained by the fact that the structure of the aggregate, produced from waste, is open-pore, aggregate has the net of formed capillaries that quickly absorb water. Therefore, during the preparation of concrete mixture with the aggregates from concrete waste, the amount of water, necessary to prepare the concrete mixture of required consistence, increases. Concrete mixtures C/3 and C/6 had equal amounts of solid components. Coarse and fine aggregate was produced after crushing concrete waste, and 15 % of cement part was replaced by the filler aggregate, produced after the crushing of concrete waste. However, larger amount of water was used in the concrete mixture C/6, water/binder ratio W/B was 0.54. After analysis of exothermic effects of such mixture it was noticed that the temperature during the hardening process decreases considerably, in comparison with the temperature of exothermic effect of mixture C/3, temperature reaches 27.73 °C. And time period, during which the maximal hydration temperature of the mixture of such composition is reached, becomes longer and reaches 18 hours and 45 minutes. Figure 8 shows the difference of the temperature variation curves during the concrete hardening period for the mixtures C/3 and C/6. When water/binder is higher, the smaller exothermic effect is achieved. However, the hardening process becomes longer, and temperature varies slower. In this case more protracted hydration process is achieved with lower hydration temperatures during the initial hardening period.

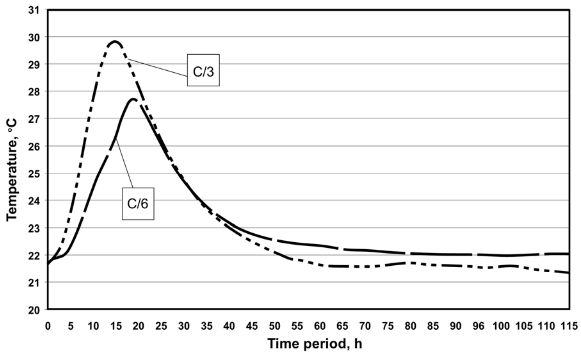

**Fig. 8.** The temperatures of the exothermic effect of the concrete during the hardening process: C/3 – concrete, with waste material and fine aggregate with 0/0.125 mm particles from crushed concrete waste, water/binder ratio is 0.52; C/6 – concrete, with waste material and fine aggregate with 0/0.125 mm particles from crushed concrete waste, water/binder ratio is 0.54

Main characteristics of exothermic effects of all concrete mixtures are provided in Table 7.

**Table 7.** Characteristics of exothermic effects

| Concrete marking | Maximal temperature of exothermic effect, °C | Time period to reach maximal temperature |
|---|---|---|
| K | 31.28 | 15 hours 45 min. |
| C/1 | 31.24 | 14 hours 30 min. |
| C/2 | 30.51 | 15 hours 35 min. |
| C/3 | 29.87 | 14 hours 38 min |
| C/4 | 30.60 | 15 hours 34 min |
| C/5 | 29.62 | 15 hours 36 min |
| C/6 | 27.73 | 18 hours 45 min. |

From the results provided in the table it becomes clear that the characteristics of hydration reaction of only two concrete mixtures are similar. These are mixtures K and C/1. Exothermic hydration reactions of other mixtures analysed take place at lower maximal temperatures, and the maximal temperature is reached after the longer time period.

## CONCLUSIONS

1. After the investigation it was determined that the hydration process, occurring during the hardening of concrete mixture, depends on the origin and size of components used to produce this composite material.
2. During the research it was analysed how characteristics of the binder change when its part is replaced by crushed concrete waste with the size of 0/0.125 mm. After a part of Portland cement is replaced by the filler aggregate, it was noticed that filler aggregate increases water demand required to prepare the paste of normal consistence, and initial set of the binder becomes longer.
3. During the hardening of the concrete, exothermic hydration reactions take place and heat that increase concrete's temperature is dissipated. Concrete's sample, where coarse and fine aggregates were replaced by the concrete waste, reached the maximal temperature slightly earlier than the concrete sample where natural aggregates were used.
4. After part of the binder is replaced by the filler aggregate, produced from the concrete sample, lower hydration temperature is reached during cement hydration, and hydration process becomes longer.
5. Results of the analysis showed that the larger W/B, the shorter inductive hydration period of Portland cement and earlier maximal exothermic temperature is reached.
6. When optimal compositions of the concrete mixture are selected and quality characteristics of the required components are obeyed, a part of natural components of concrete mixture can be replaced by the recycled materials, produced during the crushing of concrete waste.

### REFERENCES

1. **Pacewska. B, et al.** Modification of the Properties of Concrete by a New Pozzolan a Waste Catalyst from the Catalytic Process in a Fluidized Bed *Cement and Concrete Research* 32 (1) 2002: pp. 145 – 152.

2. **Soutsos, M. N., Millard, S. G., et al.** Using Recycled Demolition Waste in Concrete Building Blocks, in *Proceedings of the Institution of Civil Engeneers. Engineering Sustainbility* 157 2004: pp. 134 – 148.
3. **Tam, V. W. Y.** Parameters for Assessing Recycled Aggregate and their Correlation *Waste Management and Research* 27 2009: pp. 52 – 58. http://dx.doi.org/10.1177/0734242X07079875
4. **Vaičienė, M., Malaiškienė, J.** Expanded-clay Lightweight Concrete Dependence of Physical-mechanical Properties on Compositions *Civil and Transport Engineering* 2 (6) 2010: pp. 50 – 55.
5. **Mačiulaitis, R., Vaičienė, M., Žurauskienė, R.** Analysis of the Properties of Lightweight Concrete with the Technogenic Waste Material *Materials Science* (*Medžiagotyra*) 15 (4) 2009: pp. 363 – 367.
6. LST EN 197-1:2001+A1:2006+A3:2007. Cementas. 1 dalis. Įprastinių cementų sudėtis, techniniai reikalavimai ir atitikties kriterijai. Cement – Part 1: Composition, Specifications and Conformity Criteria for Common Cements. Lithuanian Standards Board. Vilnius, 2007: 40 p.
7. **Newman, J., Choo, B. S.** Advanced Concrete Technology. Constituent Materials. Elsevier Ltd, 2003: 288 p.
8. LST EN 196-3:2005+A1:2009. Cemento bandymo metodai. 3 dalis. Rišimosi trukmių ir tūrio pastovumo nustatymas. Methods of testing cement – Part 3: Determination of Setting Times and Soundness. Lithuanian Standards Board. Vilnius, 2009: 14 p.
9. Calcium Aluminate Cements. Cement Test Methods. Exothermic reaction (EXO). Alcoa Industrial Chemicals, 1999: 16 p.
10. **Mačiulaitis, R., Vaičienė, M., Žurauskienė, R.** Microstructure Analysis of the Structure of Materials Used for the Mixture of Expanded-clay Lightweight Concrete with Additives of Raw Material *In: The 10th International Conference "Modern Building Materials, Structures and Techniques"* 1 2010: pp. 189 – 194.
11. **Aleknevičius, M.** The Influence of Catalytic Cracking Catlyst Waste on the Aluminate Cement Hydration *Science – Future of Lithuania (Mokslas – Lietuvos ateitis)* 2009: pp. 1 – 4.
12. **Antonovič, V., Stonys, R., Pundienė, I., Prosyčevas, I., Fataraitė, E.** Investigation of Structure Formation in Complex Binder *Materials Science* (*Medžiagotyra*) 15 (4) 2009: pp. 343 – 348.

*Presented at the 13-th International Conference-School*
*"Advanced Materials and Technologies"*
*(August 27–31, 2011, Palanga, Lithuania)*