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Concrete Dust Influence on Cement Stone Properties

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The results of experimental investigation of reusing concrete dust (CD), from old concrete construction demolition as cement replacement are presented in the article. Tests were conducted on cement mass by replacing 0 % – 30 % of cement with CD mass. The physical and chemical properties of CD were stock reviewed to assess the possible influence on both fresh and hardened properties of cement. The results of qualitative properties evaluated by standard tests on different mixtures of Portland cement and CD proved to be promising. The comprehensive series of tests included rheology, compressive strength, absorbability, density, exothermic effect and rentgenographic. According to our findings CD can be used as cement replacement without strongly influencing the cement stone properties; CD can also become an alternative to ecological concrete.

Keywords: concrete dust, micro particles, recycling, cement stone, rheology.

1. INTRODUCTION

Cement is the main binder material in concrete composites. The manufacturing of cement is a energy costly process. Therefore Portland cement has a big impact on the environment due to high release of CO_2. The production of one ton of Portland cement clinker generates one ton of CO_2 emission [1].

Nowadays the cement and concrete consumption is constantly increasing as well as the concrete demolition waste. Hence it is important to find new alternatives, which help to reduce environmental pollution.

By reusing waste products from other industries, we ensure less material being dumped as landfill and more natural resources being saved [2].

A number of scientists have examined the use of fly ash as a part of cement replacement. Fly ash is an inexpensive replacement for Portland cement used in concrete while improving the strength and segregation [3 – 7]. The usual norm of replacement is between 10 % to 70 % of cement mass.

Hossain K. (2004) describes study on the suitability of volcanic pumice as the cement replacement material. The tests showed how different Portland cement – volcanic pumice powder mixes thus providing encouraging results and shows promising potential of manufacturing Portland volcanic pumice cement [8].

Similarly Silica fume can be used as a cement replacement material. The norm of additional silica fume is usually around 6.5 % to 8 % by mass. Silica fume is a by-product of the manufacture of silicon and ferrosilicon alloys obtained from high purity quartz and coal used in submerged-arc electric furnace [9]. However it must be noted that silica fume is a quite expensive material [10].

Ground granulated blast furnace slag, which is a waste product in the manufacture of pig iron, is yet another cement replacement material. According to [9], every ton of pig iron produces 300 kg of slag. T. Taruya (2002) discuses the method of supplying sewage sludge as raw material for cement [11].

However raw materials such: fly ash, volcanic pumice, silica fume, pig iron need to be imported. This reason determine bigger price of them. The alternative could be to change these expensive micro-fillers by micro-filler from concrete demolition wastes.

Given this situation, possibility of reducing CO_2 emission during the production of Portland cement comes from reusing concrete demolition as raw material. A number of scientists have also examined the use of different waste products in manufacturing of building material with respect to energy and natural resource consumption [12 – 16]. However concrete demolition waste is used only as small and course aggregates. Where as the smallest particles are usually discharged as a waste.

We are not aware of other experiences available in the literature in using these smallest particles from concrete demolition waste as micro-filler. For this reason a wider comparison was not possible.

In this article we explore the usage of these small concrete dust (CD) particles which are acquired from concrete demolition waste as Portland cement replacement.

2. EXPERIMENTAL APPROACH

Tests on cement pastes and hard cement have been carried out in order to explore the effect of Portland cement being partially replaced by CD.

The scheme of the experimental program in this research was done as following: five different ratios of CD replacement were mixed, i. e., 0 %, 10 %, 15 %, 20 % and 30 %.

For each mixture of cement and CD were blended with forced mixer "Automix 65-L0006/A" at various speeds for 120 s.

Specific surface area of Portland cement and CD were measured by using a Blaine apparatus by LST EN 196-6 standard.

CD particles size distribution was tested with a "Mastersizer 2000" apparatus. During the laser diffraction

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measurement, particles are passed through a focused laser beam. These particles scatter light at an angle that is inversely proportional to their size. The scattering of particles is predicted by the Mie scattering model. Measuring range is from 0.02 µm to 2000 µm.

The influence of CD replacement on water demand and the times of initial and final settings of the pastes were studied using a Vicat apparatus according to EN 196-3. For standard consistency the Vicat plunger should penetrate to a point 6 mm ±2 mm from the bottom of the Vicat mould. The initial setting time occurs when a penetration of 25 mm is obtained. At the time of final set the needle should not sink visibly into the paste.

The rheological properties of cement and CD mixtures were examined with the coaxial cylinder rotational viscometer ”Rheotest-2”. Cement slurries with CD replacement were tested for two main rheological characteristics: yield stress and plastic viscosity [17]. All cement slurries were prepared with the same water/cement ratio – 0.4. The viscosity of cement slurry was estimated using different inward cylinder rotation rates, i. e., 656 l/s, 364 l/s, 218 l/s, 121 l/s, 73 1/s.

For determining the strength of the cement stone, the standard (40×40×160) mm prisms were shaped. After the casting of the cement and CD paste the mould was sealed off with a glass plate. After a curing period of 24 hours the prisms were placed in water with a constant temperature of 20 °C. After 28 days the strength and density were tested.

Specimens were also tested for determination of water absorption kinetics analysis by GOST 12730.4-78 standard. In order to determine the absorbability of water first specimens were desiccated in 50 °C for two days, then refrigerated and weighted. Thereafter the specimens were soaked in water and weighted after 15 min, 30 min, 1 day and 2 days.

X-ray diffraction measurements were carried out with CuK_a radiation ($l = 0.15405$ nm) on a diffractometer DRON-6 (Russian design) operating at 35 kV and 20 mA equipped with a single-crystal graphite monochromator in step scanning mode of 0.02° in $2q$ and counting time of 0.5 s per step.

The thermographic research of the exothermic effect was tested for the cement pastes with different amounts of CD replacement. For this test the thermocouple data logger “TC-08” was used. The test was carried out at room temperature (20 ±2) °C. To make specimens the 105 g of each mixture paste was poured into plastic containers and the thermocouples were placed inside. The specimens were isolated with a polystyrene cover 50 mm thick. The temperature changes of the cement pastes were recorded continuously during the hardening process.

3. MATERIALS USED

The following materials we used during the experiments: Portland cement CEM I 42.5R produced by the JSC “Akmenės cementas” which is produced according to the EN 197-1 standard, i. e., “Cement - Part 1: Composition, specifications and conformity criteria for common cements”. The density of cement particles are 3110 kg/m^3. The specific surface area of the cement was 3962 cm^2/g.

The smallest particles from the demolition waste of concrete structures are concrete dust.

The size of CD varies from smallest particles to 0.125 mm. CD has a specific surface area of 5047 cm^2/g and a specific density of 2570 g/cm^3. Granulometric composition of CD particles is shown in Fig. 1.

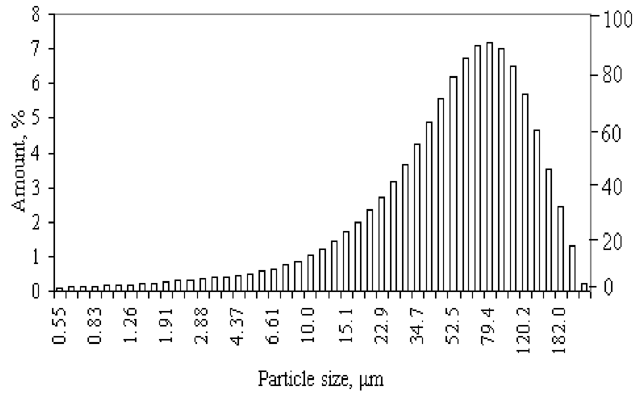

Fig. 1. CD particles size distribution

CD was acquired from old concrete blocks of class C30/37. Smaller parts of this concrete blocks were crushed with a mechanic alligator until the size of 10 mm was reached. Crushed concrete was sieved in a succession through 10 mm > 5 mm > 2.5 mm > 0.8 mm > 0.125 mm bolters. The acquired CD particles were used as replacement of the Portland cement.

4. RESULTS AND DISCUSSIONS

The physical and mechanical properties of different cement and CD mixtures are discussed in this chapter.

4.1. Water demand and initial and final setting time of cement pastes

The results of water demand for each blended mixture is shown in (Fig. 2). To obtain the correct water amount required for normal cement paste consistency, the Vicat apparatus’ beam should stick up by 6 mm ±2 mm.

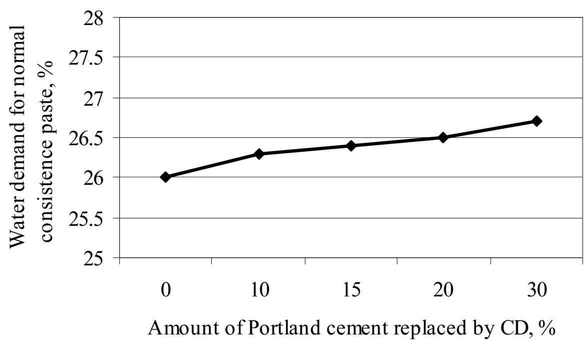

Fig. 2. The dependency of water demand for normal cement paste consistency from amount of Portland cement replaced by CD

The relation between CD and water/(cement and CD) shows that increasing the amount of CD replacement, increases water demand. The water percentage required to maintain a normal consistency increases insignificantly though. CD replacement in cement paste by the ratios of 10 %, 15 %, 20 % and 30 % have increased water demand of 0.9 %, 1.3 %, 1.9 % and 2.9 % respectively. This increase may be related to the specific surface area of the CD's which is bigger then cement's. The water demand of the normal cement paste without CD addictives is 26.0 %.

By comparing these results with other authors' works we recognize that CD admixture increased water demand less than other micro-fillers such as silica fume, volcanic pumice, fly ash. While limestone and granite fines reduce water demand in cement paste [18, 19].

The relation between CD replacement and the initial and final setting times are shown in Fig. 3. For each mixture the constant amount of water was used.

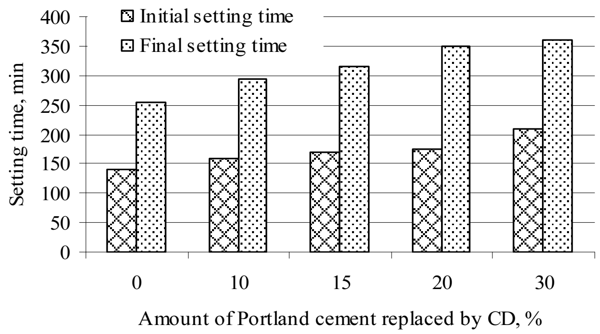

Fig. 3. Initial and final setting time of cement paste and pastes with CD

The result in Fig. 3 shows that CD replacement prolongs initial and final setting times of cement paste. It means that CD particles are less active than cement particles and prolong the hardening process of cement paste. By comparing these results with other authors' works we ascertain that CD admixture prolongs setting times similarly as others inert micro-fillers [19, 20].

4.2. Relation between CD mixtures and rheological properties of cement slurries

The results of velocity over shear stress of cement slurry with different replacements of CD is charted in Fig. 4.

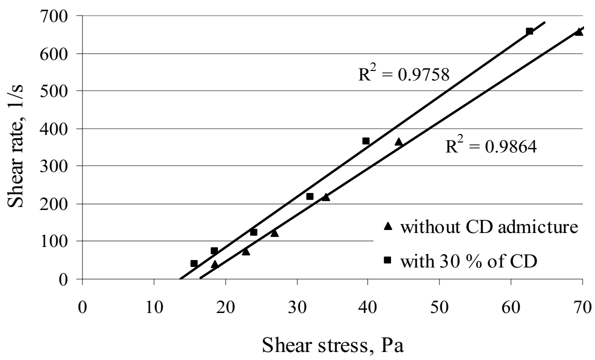

Fig. 4. Flow curves of cement slurry and cement slurry with CD replacement

The reduction of cement slurries shear stress for 30 % CD replacement paste is insignificant. The flow curves of cement slurry and cement with CD are mostly resembling linear dependency. Therefore these slurries can be defined as Bingham fluids [21]. The gradient resulting from the velocity dependency over shear stress yields a correlation coefficient (R^2) of 0.9864 for cement without admixture and 0.9758 for 30 % admixtures.

The dependency of different CD amount as cement replacement on yield stress of cement slurry is shown in Fig. 5.

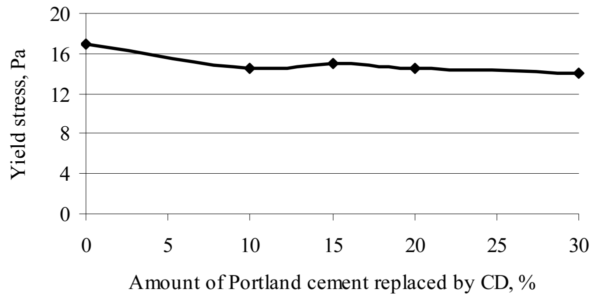

Fig. 5. The dependence of yield stress of cement slurry from different CD amount as cement replacement

The result in Fig. 5 reveals that CD additive reduces the yield stress of cement slurry marginally. 10 % of CD additive decreases yield stress about 14 %. However the larger dosage of CD admixture has no significant effect on the yield stress of cement slurry.

The dependency of different dosages of CD admixtures on viscosity of cement slurry tested at different shear rates is shown in Fig. 6.

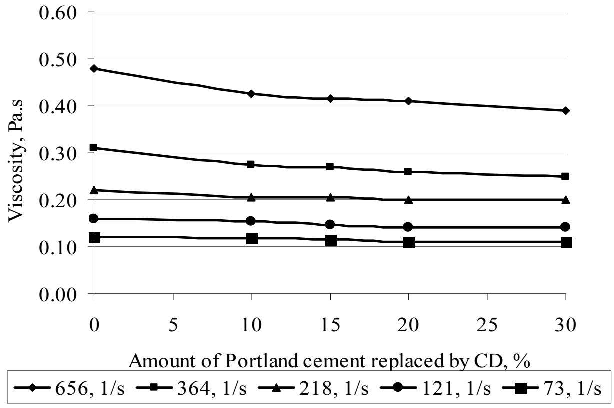

Fig. 6. The dependence of viscosity of cement slurry at different shear rates of different CD amount as cement replacement

CD replacement reduces the viscosity of cement slurries at all different shear rates. The viscosity is most significantly reduced at 656 1/s shear rate. The difference between viscosity of cement slurries without CD admixture and with 30 % of CD admixture is 18 %. Reductions at other levels of shear rates are insignificant. We are not aware of other research on CD influences on rheological properties. The obtained results are similar to other authors' works with different micro-fillers [19 – 22].

4.3. Compressing strength test

The Fig. 7 shows how different portions of CD in cement stone as cement replacement impact the compressing strength. Specimens were tested according to the LST EN 196-1 standard. Apparently CD replacement in cement stone by the following ratios of 10 %, 15 %, 20 % and 30 % reduces compressive strength by 6 %, 15.6 %, 28 % and 39.6% respectively.

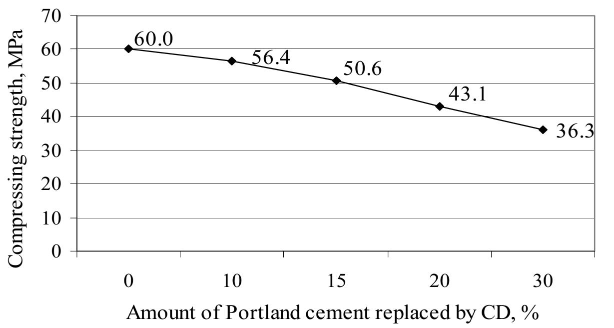

Fig. 7. The dependence of compressive strength of cement stone on different dosage of CD

Cement is often overused in the manufacturing of concrete composites. This is due to cement which is used as small-filler and concrete class being bigger than designed. Small particles are necessary for the granulometric composition in concrete for filling the gaps between bigger particles. Hence it is rational to use CD partly as cement replacement. The dependency of different dosages of CD admixtures on cement usage coefficient is shown in Fig. 8. Cement usage coefficient shows whether cement is used economically to reach due compressing strength.

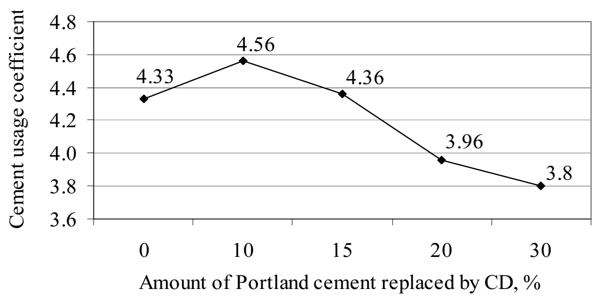

Fig. 8. The dependence of cement usage coefficient on different dosage of CD

The results in Fig. 8 reveals that replacing cement by CD to 15 %, the cement usage coefficient obtainable bigger than in the specimen without CD addictives. The cement usage coefficient is compared between the amount of cement which was used for one constant volume specimen and reached compressing strength after 28 days hardening.

4.4. Density test

CD particles are lighter than cement particles. This has fair impact for cement stone density. The result of the cement stone density test is showed in Fig. 9. The CD replacement in cement stone by the ratios of 10 %, 15 %, 20 % and 30 % reduces cement stone density by 2.6 %, 3.2 %, 3.4 % and 5.1 % respectively. The biggest density drop-off was then cement replaced by 30 % of CD.

Determined impact for cement stone diminished density was CD specific density, which is 2570 kg/m^3. Cement specific density is about 3100 kg/m^3. All specimens were prepared with the same water/cement ratio – 0.4.

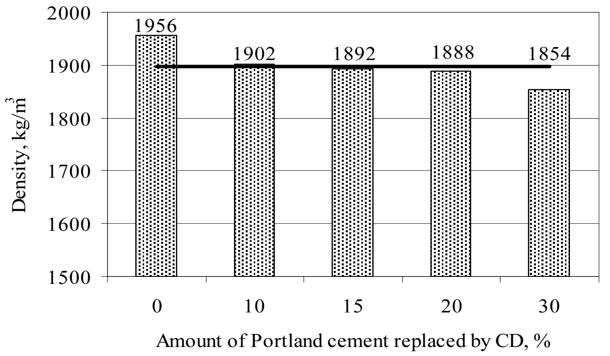

Fig. 9. The dependency of cement stone density (kg/m^3) on different dosages of CD

4.5. Influence of CD admixtures on cement stone hardening process

Cement stone porosity parameters were evaluated according to water absorption kinetics and are presented in Table 1. Using the methodology of water absorption kinetics were determining the following parameters: open porosity, closed porosity, full porosity, and the size of capillary pores described by two comparative rates, i. e., λ which is the average rate of open capillary pores, and α which is the homogeneity rate of capillary pores.

Table 1. The variation of water demand and porosity of hardened cement stone, modified with CD

Properties of cement stone	The portions of cement replaced by CD admixture			
	0 %	10 %	20 %	30 %
Open capillary pores average rate, λ	4.20	4.12	3.80	4.38
Capillary pores homogeneity rate, α	0.50	0.54	0.64	0.67
Full porosity, %	22.69	26.81	28.03	32.20
Closed porosity, %	5.91	7.79	7.62	9.75
Open porosity, %	16.78	19.03	20.41	22.46
Water absorption, %	9.23	11.23	12.34	14.41

CD admixture has no strong influence on the porosity properties of cement stone, but it slightly improves porosity and the homogeneity rate of capillary pores. It also reduces pores which has positive influence on cement stone durability.

4.6. The study of exothermic effect during hardening process dependence on CD admixture in cement paste

The measurements of the exothermic effects on the cement mixture with the CD admixture during the hardening process are given in Fig. 10. The cement paste releases heat during the hydration process. The temperature differs at various stages of the cement's hydration stage.

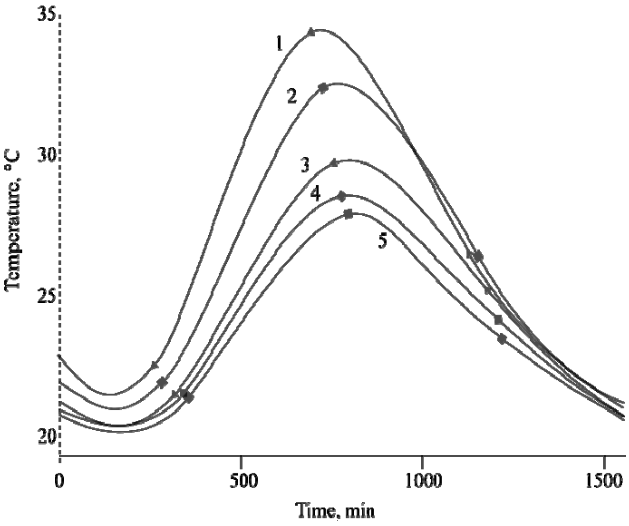

Fig. 10. The temperatures of the exothermic effect on cement with CD admixture pastes during the hardening process. Note: 1 – specimen without CD admixture; 2 – specimen with 10 % of CD admixture; 3 – specimen with 15 % of CD admixture; 4 – specimen with 20 % of CD admixture; 5 – specimen with 30 % of CD admixture

Results show that during the hydration process the temperature of the cement mixture without CD reached the highest peak at 34 °C. The more cement is replaced with CD the less temperature is released. The specimen with 30 % of CD admixture reached 27.5 °C temperature. The specimen without CD admixture reached it's maximal exothermic temperature after 690 min. The CD replacement in specimens by the ratios of 10 %, 15 %, 20 % and 30 % reach their highest exothermic temperatures after 710 min, 745 min, 770 min and 795 min. respectively. The results of the analysis showed that the larger the percentage of CD replacement is in specimens, the longer the time of the hydration of the Portland cement is reached, also the lower exothermic temperatures are reached measurements.

4.7. The influence of CD admixture on cement stone hardening process

The influence of CD admixture on cement stone hardening processes has been analyzed by the X-ray diffraction method. Four specimens were chosen, i. e., cement stone that Portland cement was replaced by 10 %, 20 % and 30 % of CD admixture and without CD admixture. As a starting point, the test specimens were dried at 105 °C and sieved with sieve No. 008. The X-ray diffraction patterns in specimens with CD admixture and without CD admixture are shown in Fig. 11.

According to the results obtained we may state that qualitative composition of examined cement stone does not change particularly with the variation of CD admixture portions. The more cement is replaced with CD the less hydro silicates can be found after the hardening process.

Consequently, more dolomite, quartz and calcite can be found. It is because CD contains more filler aggregates than cement stone. The data of quantitative assessment of the research results and the measurements of the relative height of the nodes of respective compounds are presented in Fig. 11.

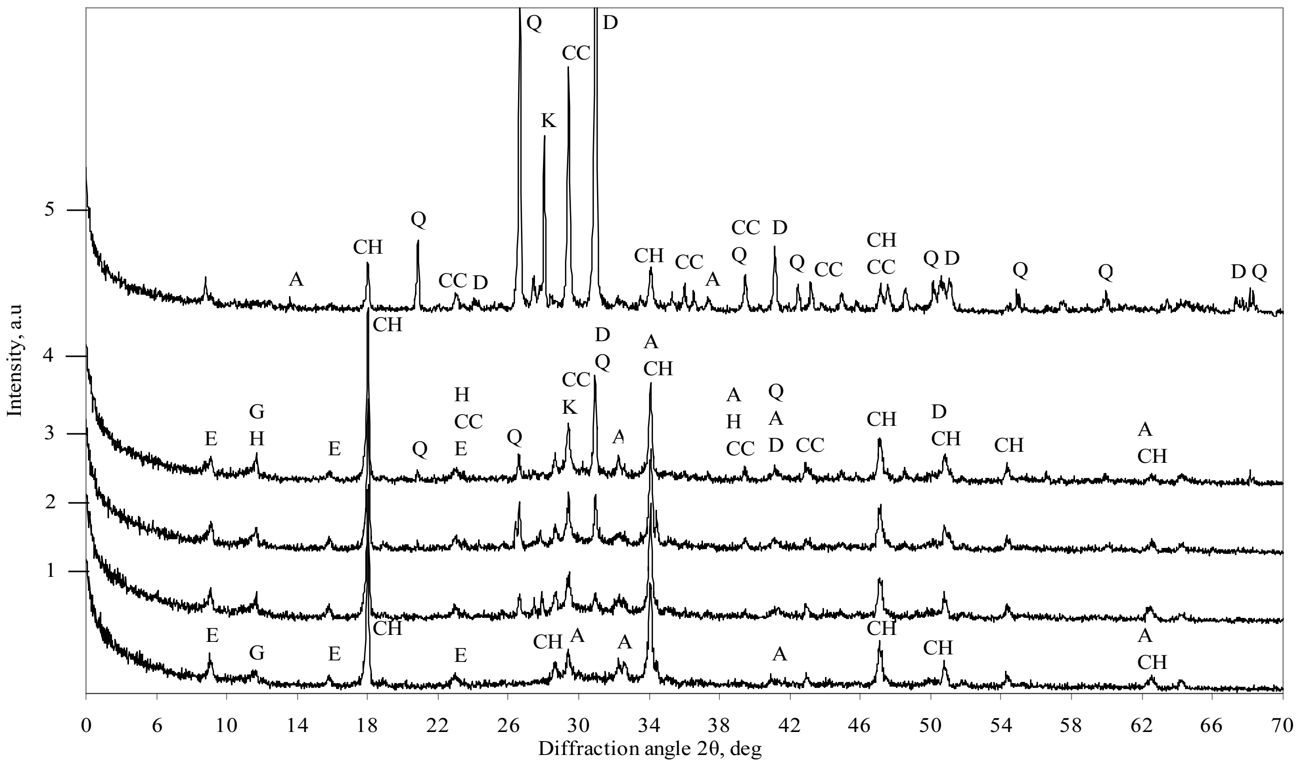

Fig. 11. X-ray diffraction patterns of cement stone that has reached 28 days of natural hardening. E – the peaks of etringite. G – the peaks of gypsum. CH – the peaks of portlandite. A – the peaks of tricalcium silicate. CC – the peaks of calcite. K – the peaks of calcium hidrosilicates. Q – the peaks of quartz. D – the peaks of dolomite. H – the peaks of hidrotalcite. In the legend: 1 – specimen without CD admixture; 2 – specimen with 10 % of CD admixture; 3 – specimen with 20 % of CD admixture; 4 – specimen with 30 % of CD admixture; 5 – CD specimen

5. CONCLUSIONS

1. The results obtained from the experiment shows that CD replacement prolong the time between the initial and final setting of the cement paste. The exothermic temperatures decrease with the increasing portion of CD admixture during the hardening process.
2. The test results prove that replacing cement up to 30 % of CD admixture reduces the yield stress to 15 % and viscosity to 18 %.
3. In economical terms it's viable to replace cement by CD up to 15 %, because cement usage coefficient obtainable bigger than in specimen without CD addictives.
4. Rentgenographic analysis shows that CD admixture increases dolomite, quartz, calcite and decreases hydro silicates for qualitative composition of cement stone.
5. It's possible that CD addictives increase cold resistance of cement stone, because close porosity increases to 65 % and pores become more homogeneous.
6. New possibilities how to utilize CD waste in cement products without changing their characteristics was found.

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