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MECHANICAL PROPERTIES OF CEMENT PASTE WITH 50% FLY ASH AT HIGH TEMPERATURES

O. Zobal[*], R. Lovichová[**], P. Padevět[***]

Abstract: *The current trend in society is the broader and appropriate use of waste materials. In the construction industry, for example, this effort is represented by using a larger quantity of power plant fly ash in cement and concrete mixtures. This article is dedicated to the comparison of the mechanical properties of a reference cement paste and binders where 50% of cement is replaced by power plant fly ash at high temperatures. Specifically, the experimentally obtained density values, compressive strength, tensile strength and static modulus of elasticity are presented here. The specimens for the experiment were 28 days old and the water-binder ratio was 0.4.*

Keywords: ***Cement, fly ash, high temperatures, compressive strength, tensile strength.***

1. Introduction

Society tries to follow the principles of sustainable development. This applies to all areas of society, including the construction industry. All of them are trying to behave economically and ecologically. One of the ways recommended to accomplish this is to use waste material. One of the waste materials is fly ash from power plants. Power plant fly ash can be well used in cement and concrete mixtures. The Czech Republic is one of the largest producers of power plant fly ash per capita in the world. Coal combustion produces around 50% of energy in the thermal power plants in the Czech Republic, which is well above the average in relation to the world and to Europe. Around 8 million tons of fly ash are produced in the Czech Republic every year.

Power plant fly ash is a heterogeneous material, which is made up of particles with the size of 0 to 1 mm. Individual particles can have very different physical, chemical and mineralogical properties. These properties are influenced by the quality of burnt coal and by the combustion technology process. Data were collected from available literature, showing the effects of fly ash on the physical and mechanical properties of the final product. Around 60% of cement was replaced by fly ash. What follows is a list of selected concrete properties and the effect of added fly-ash on the resulting material:

1) positive effect: concrete hydration heat, shrinkage when drying out, creeping, price

2) negative impact: variability of fly ashes properties, increase of initial strength, delayed start of setting, carbonation, water absorption

Fly ash has been added to concrete to a greater or lesser extent for several decades. One of the most suitable applications to massive structures is the reduction of hydration heat. An excellent example is one of the most important structures on the territory of the Czech Republic, namely the Orlík Dam. Analysis confirmed the excellent properties of the concrete that was used for the production of the dam body of the Orlík Dam. The resulting concrete is a very compact material having a minimum of voids and pores with high strength, which is still growing over time. That's a very positive fact. This analysis has shown that the replacement of nearly 30% of cement by fly ash has had no negative effect on the long term properties of the resulting concrete.

[*] Ing. Ondřej Zobal: Faculty of Civil Engineering, CTU in Prague, Thakurova 7, 166 29, Prague; CZ, e-mail: ondrej.zobal@fsv.cvut.cz

[**] Bc. Romana Lovichová: Faculty of Civil Engineering, CTU in Prague, Thakurova 7, 166 29, Prague; CZ, e-mail: romana.lovichova@fsv.cvut.cz

[***] Ing. Pavel Padevět, Ph.D.: Faculty of Civil Engineering, CTU in Prague, Thakurova 7, 166 29, Prague; CZ, e-mail: pavel.padevet@fsv.cvut.cz

2. Interaction between the cement and fly ash

After mixing cement with water, hydration occurs and there is a C-S-H gel giving subsequently rise to portlandite (Ca (OH) 2). The C-S-H gel creates an alkaline environment in the mixture which activates fly ash and produces an additional type of gel. Fig. 1 shows a sample of the cement paste which contains 100% of cement (CEM I 42,5 R) and 0% of fly ash. The cement-water ration has a value of 0.4. The age of the sample is 120 days.

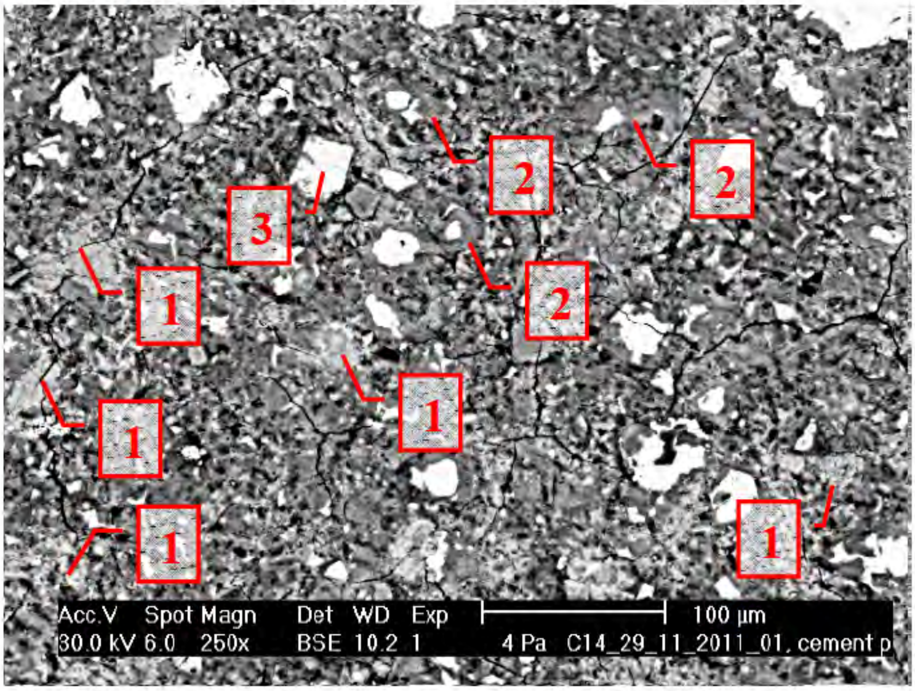

Fig. 1 Microscopic image of cement paste – composition 100% cement CEM I 42,5 R, 0% fly ash, 120 days old: 1) Ca(OH)2 – portlandite 2) C-S-H gel 3) clinker C2S - belit

Fig. 2 shows a sample of the cement paste which contains 50% of cement (CEM I 42,5 R) and 50% of fly ash. The cement-water ratio with fly ash has a value of 0.4 and the age of 120 days. Here you can see the porous grains of ash, less portlandite which ceases to exist during the reaction of fly ash with the C-S-H gel.

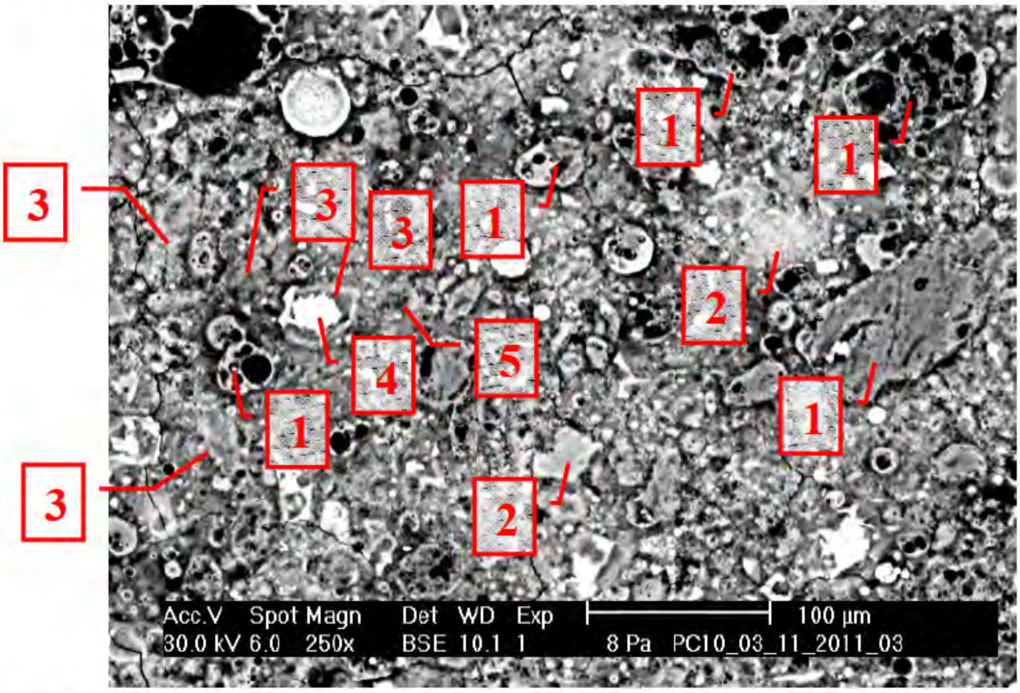

Fig. 2 Microscopic image of cement paste – composition 50% cement CEM I 42,5 R,50% fly ash, 120 days old 1) fly ash 2) Ca(OH)2 3) C-S-H gel with fly ash 4) clinker C3S – alit 5) C-S-H gel

3. Methodology and evaluation of the experiment

The first mixture (referred to as CFA 1000 sat) was produced using the cement CEM I 42, 5R from Radotín and a given amount of water. The second mixture was made from the same cement and 50% of cement by weight was replaced by fly ash from Mělník referred to as EME et EN 450. This mixture is referred to as CFA 5050 sat and CFA 5050 dry, depending on whether the specimens were stored in a water bath or dried at 105 °C before testing. The water-binder ratio was always 0.4 and the age of the test samples was 28 days. Test samples had the shapes of small beams with sides of 20 x 20 mm and a length of 100 mm.

Two mechanical tests were carried out on the specimens – compressive strength and flexural strength were determined. The electro-mechanical test machine MTS Alliance RT-30 with a maximum load force of 30 kN in pressure and tension was used for the experiment. In addition, a strain gauge to measure the unit strain was attached to each body to determine the static modulus of elasticity. The beams for testing the flexural strength remained unchanged. It was a three-point bending strength test where the load was in the middle of the body and the effective length was 80 mm. Then the halved and aligned parts of the beams were used for the compressive strength test.

The experiment regarded the influence of high temperatures on the mechanical properties of the cement paste. Therefore, the specimens were subjected to increasing temperature. The following temperatures were selected as basic temperatures: 20°C (basic temperature); 200°C (free water expulsion); 450°C (disintegration of clay); 600°C (disintegration of portlandite). Intermediate temperatures of 300°C and 400°C were inserted between these values for supplementation. The surface of specimens was damaged more considerably in the case of the cement paste without fly ash than in the case of specimens where fly ash was added to the mixture. The specimens were heated in regular cycles – the temperature was increased by 100°C every 10 minutes and the specimens were heated at a constant temperature for 2.5 hours.

3.1. Volume weight

Each body was measured and weighed after being removed from water and heated to determine the value of the density. Fig. 3 shows a graphical representation of the development of density, depending on the temperature and type of mixture. The assumption was confirmed that the density of the specimens from the cement paste without fly ash significantly decreases with increasing temperature. The density of the mixture with 50% fly ash, with the bodies being saturated, has a lower value of approximately 20% at 20°C than the value of the mixture without fly ash. The density hardly changed when heating the mixture with fly ash either saturated or dried. The measured values were statistically evaluated and the standard deviation did not exceed 5%.

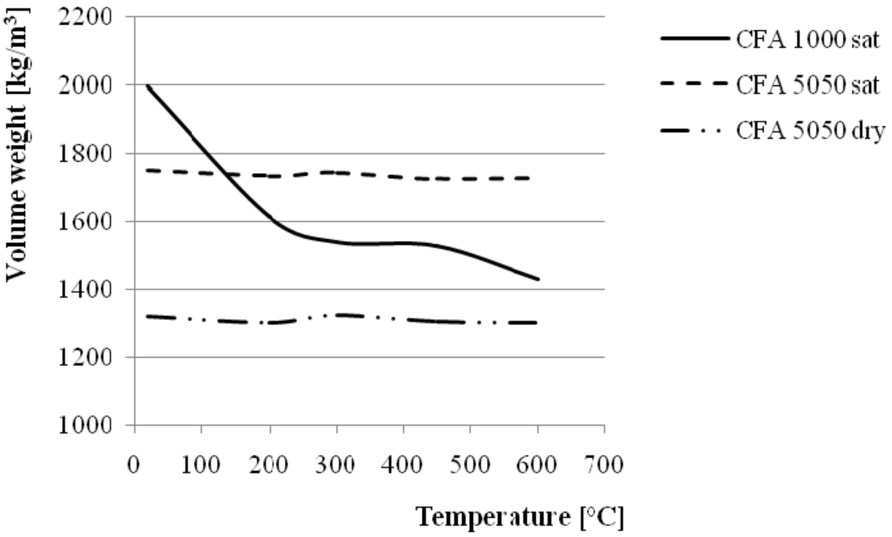

Fig. 3: Graphical representation of development density with respect to time and the type of mixture, the ratio of water and the binder has a value of 0.4, and aging specimens for 28 days

3.2. Compressive strength

Fig. 4 shows the average values of compressive strength of the cement paste specimens without fly ash (standard deviation was not greater than 5%). It is obvious that the assumption of declining values with increasing temperature was not proven because there was an increase as compared to values at 20°C when the specimens were heated to 200°. The values are already dropping fast at other higher temperatures. The compressive strength of specimens made from paste with fly ash was already reduced by about one half at 20°C. The decrease with increasing temperature, however, wasn't as quick and significant for these mixtures. In addition, there was no increase in strength until about 300°C.

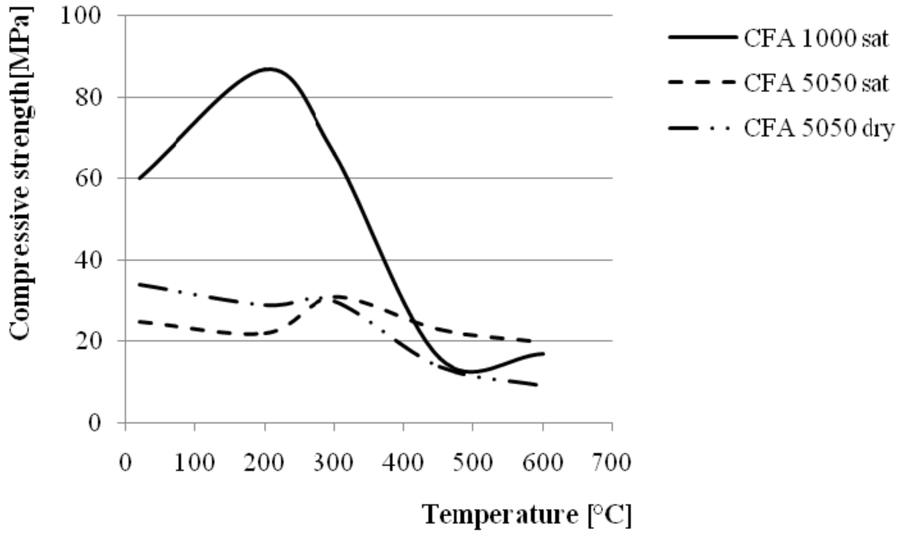

Fig. 4: Graphic representation of the development of compressive strength versus time and the type of mixture, the ratio of water and the binder has a value of 0.4, and aging specimens for 28 days.

3.3. Tensile strength

Values for another monitored mechanical property – tensile strength -, measured on the beams, can be seen in Figure 1. 4. Once again, these are average values with a standard deviation of less than 5%. The results show the same trend as for compressive strength. However, the change occurred in mixtures where one half of the cement weight was replaced by fly ash. Here higher values can be seen at the basic temperature of 20°C as compared to the reference cement paste without fly ash.

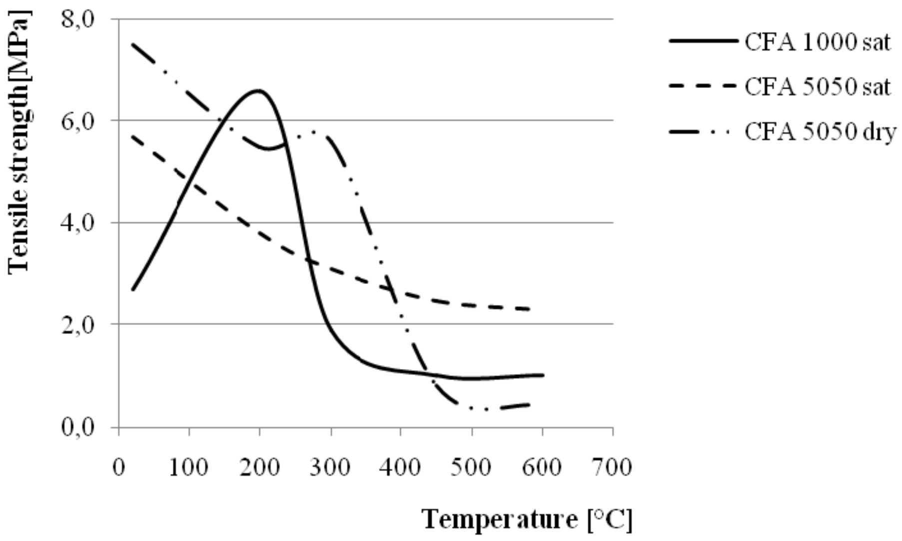

Fig. 5: Graphical representation of the evolution of tensile strength depending on the time and type of mixture; ratio of water and binder has a value of 0.4 and age of specimens is 28 days.

3.4. Static modulus of elasticity

Using a strain gauge, the proportional deformation was measured and thus the static modulus of elasticity could be calculated. The average values (standard deviation was not more than 5%) can be seen in Figure 5. Compared to strengths, there is no increase in values around 200°C. On the contrary, we can follow their decline. The highest values were again measured in the case of cement paste without fly ash, less than 40 GPa at 20°C. A value almost less by half was measured in the case of the CFA 5050 sat mixture and almost less by two thirds for mixtures of CFA 5050 dry.

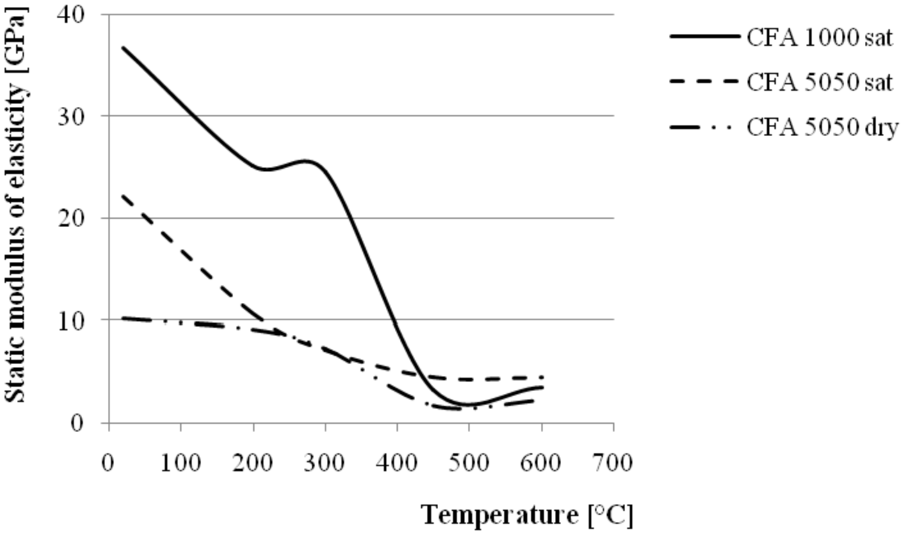

Fig. 6: Graphical representation of the evolution of static elastic modulus depending on the time and type of mixture; ratio of water and binder has a value of 0.4 and age of specimens is 28 days.

4. Conclusions

The subject of the experiment was the mechanical properties of cement paste and cement pastes with a 50% share of fly-ash in a mixture affected by high temperatures. The results of individual measurements and calculations were statistically processed and compared with each other. Test specimens in the form of beams were produced from the cement paste. Dimensions were always measured for all specimens and the weight was determined in order to obtain the necessary information about changes in the density of the tested material. Cement paste was prepared from CEM I 42.5 R , fly ash EME et EN 450 with the water-binder ratio value of 0.4. The testing of specimens was performed at five temperatures: 20°C, 200°C, 300°C, 450°C and 600°C. The assumption was that the mechanical properties would deteriorate with increasing temperature because the structure of specimens would be damaged. Surface damage of cement paste without fly ash at temperatures of 450°C and more was considerable, but the added fly ash significantly mitigated this damage.

Although fly ash is produced as waste during power generation, lately it has already found a relatively broad application in various sectors. The largest part of the fly-ash is used in the construction industry. Fly ash is produced by burning coal in thermal power plants and the Czech Republic is one of its largest producers per capita in the world. Problems arise with such a high production, of course, and it is therefore necessary to deal with this material. This is a heterogeneous material whose properties are directly proportional to the characteristics of the burnt material, and subsequently to the type of the combustion process.

If ash is added to cement and concrete mixtures, it affects, of course, the characteristics of the resulting material. Considering the positive impact, the fact that fly ash added to the mixture reduces the value of hydration heat has already been used for decades. Another advantage is the reduction in the price, as well as a positive influence on the development of the material during shrinkage and creeping. One of the biggest problems is the variability of fly ash properties, and further the delay of the commencement of solidification and the growth of initial strength as well. At present, a problem, the water absorption of fly ash, has occurred during the processing of mixtures.

The aim of further work is to address problem areas in more detail, specifically, the variability of fly ash and the determination of limits for each of the properties, in addition, water absorption which is not dealt with very much in available literature as well as the positive effects of fly ash when added to mixtures, and to define criteria for them for different purposes of use in the building industry. Work would start on cement mixtures by replacing cement pastes by fly ash in the range of 30 to 70% (80%), to mortar and, if time and technological sophistication of the experiments allow it, concrete mixtures would be addressed as well. Experiments will be supported by a variety of simulations.

Acknowledgement

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