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Combination of Standard Secondary Raw Materials and New Production Waste Materials in Green Concrete Technology

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***Abstract*—**This paper deals with the possibility of safe incorporation fluidised bed combustion fly ash (waste material) into cement matrix together with next commonly used secondary raw material, which is high-temperature fly ash. Both of these materials have a very high pozzolanic ability, and the right combination could bring important improvements in both the physico-mechanical properties and the better durability of a cement composite. This paper tries to determine the correct methodology for designing green concrete by using modern methods measuring rheology of fresh concrete and following hydration processes. The use of fluidised bed combustion fly ash in cement composite production as an admixture is not currently common, but there are some real possibilities for its potential. The most striking negative aspect is its chemical composition which supports the development of new product formation, influencing the durability of the composite. Another disadvantage is the morphology of grains, which have a negative effect on consistency. This raises the question of how this waste can be used in concrete production to emphasize its positive properties and eliminate negatives. The focal point of the experiment carried out on cement pastes was particularly on the progress of hydration processes, aiming for the possible acceleration of pozzolanic reactions of both types of fly ash.

***Keywords*—**High-temperature fly ash, fluidised bed combustion fly ash, pozzolanic, CaO (calcium oxide), rheology.

I. Introduction

THE modern concrete technology offers a wide range of different types of concrete, taking into account the specific requirements of the designers and the technical solution of building construction These specific requirements are the reason for the continuous development and innovation of this material as well as the production technology itself. The field of high-performance concrete is trying to optimise the composition of the material so as to maximise its positive properties for sustainable construction while minimising the negative environmental impacts throughout its life cycle. Standard components of concrete are also supplemented by other components in the form of active or inactive admixtures which also contribute to the resulting properties of the concrete. The use of admixtures in concrete results not only in economical saving, but also in secondary or waste materials that are often used as admixtures, raising ecological issues.

There has been an increasing focus on the issue of preserving the most environmentally friendly environment. This is also associated with the continued pressure on emission reductions, especially in the construction or energy industry. A large part of the secondary energy products generated by thermal energy production nowadays are used as full-value raw material in the construction industry. The reduction of such emissions in the energy industry has brought about many measures and binding regulations to comply with the requirements of the European Union or global regulations regarding emission limits. That's the reason why many thermal power plants are constantly investing in new combustion technologies to reduce emissions that pollute the air and switch to technologies that meet environmental requirements and legislation [1]. With such new technologies, emissions have decreased significantly, but it made way for the creation of a new energy by-product. In addition to commonly used ash in concrete technology, the new product was created thanks to new combustion technologies, which are now not used for concrete production. Although it is an admixture with pozzolanic properties, the use of fluidised fly ash in the technology of concrete is not common [2]. This is due to its different chemical composition compared to high-temperature ash as well as its fluctuating properties due to different combustion technologies.

The pozzolanic properties of high-temperature fly ash are considered a significant advantage, and its stable chemical composition makes it a good admixture for cement composite. In comparison, the chemical composition of fluidised bed combustion fly ash is variable. The biggest difference is the amount of free CaO together with sulfates, which are higher in fluidised bed combustion fly ash. This can be solved by mixing fluidised bed combustion fly ash with water before adding it to the cement composite. Free CaO reacts with water to create $Ca(OH)_2$, and this, to some extent, is an activator for the beginning of the faster pozzolanic reaction. When high-temperature fly ash and fluidised bed combustion fly ash are used in the right ratio, they can accelerate the pozzolanic reaction of high-temperature fly ash in the same manner.

The main objective of the experiment is primarily the application of this raw material to the production of concrete with the interest to achieve more favourable environmental properties within the concrete with regard to the use of waste materials.

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II. Characteristics of Waste Products Created during Coal Combustion

As mentioned before, the combustion of coal in thermal power plants generates, besides electricity, a secondary energy product, referred to as power plant fly ash. The use of this type of admixture has been known throughout the world for many years, and, on the basis of its positive properties, it has become more and more widespread. In the concrete industry, these substances are used in the production of mixed cements or in an admixture for the production of traditional concrete as well as untraditional ones, like aerated concrete or for the production of expanded aggregate [3].

At present, we can distinguish (at least) two coal combustion technologies. In both cases, a secondary product is created which is considered an active admixture for concrete.

Particularly different temperature of high temperature and fluid combustion and desulfurization of flue gas leads to different properties of high temperature and fluidized bed combustion ash. The classic combustion of grinded coal takes place at a temperature of 1200-1700 °C. High-temperature fly ash is formed by spherical silica glass particles that are trapped in electrostatic precipitators during combustion. The properties that fly ash must meet are defined in the standard EN 450-1 Fly ash for concrete.

Fly ash for concrete is possible to use in multiple variants. To influence the rheology of fresh concrete, it is possible to use high-temperature fly ash as a micro-filler. In fresh concrete, the presence of ash provides better workability, which is obtained especially by the spherical shape of the fly ash. The fly ash functions as a micro filler, ensuring a denser structure of cement stone, and, after hardening of the entire composite, a cohesive unit is created with better mechanical properties. However, fly ash plays a more important role from a chemical point of view. Fly ash, as an active pozzolan, reacts in an aqueous medium in the presence of calcium ions forming hydration products: CSH gels.

The second type of combustion is the so-called low-temperature combustion, with combustion temperatures of 800 -850 °C. [4] This technology enables efficient desulphurisation to reduce the emission of harmful emissions into the air. The pollutant is disposed of directly in the boiler, when the ground fuel is combusted with the admixture of lime (or dolomite) in the circulation layer. Different combustion temperatures and desulphurisation are the reasons for the creation of different fly ash, as is the case with high-temperature combustion. Due to the lower temperature of combustion, the unreacted CaO is present in the form of so-called soft burnt lime and is therefore reactive.

Fluidised bed combustion fly ash is also characterised by the absence of a melt produced at temperatures above 950 °C. In this case, only sintering takes place and the fly ash has grains of irregular shape with a porous structure. Physical properties such as density and specific surface area are also distinctly different. Normally reached values of specific weight range between 2500 and 3000 kg/m^3. As an example, the value of the specific surface can serve as the value of the fluidised bed combustion fly ash Tisová, as determined by BET analysis, which is 8,09 m^2/g [5].

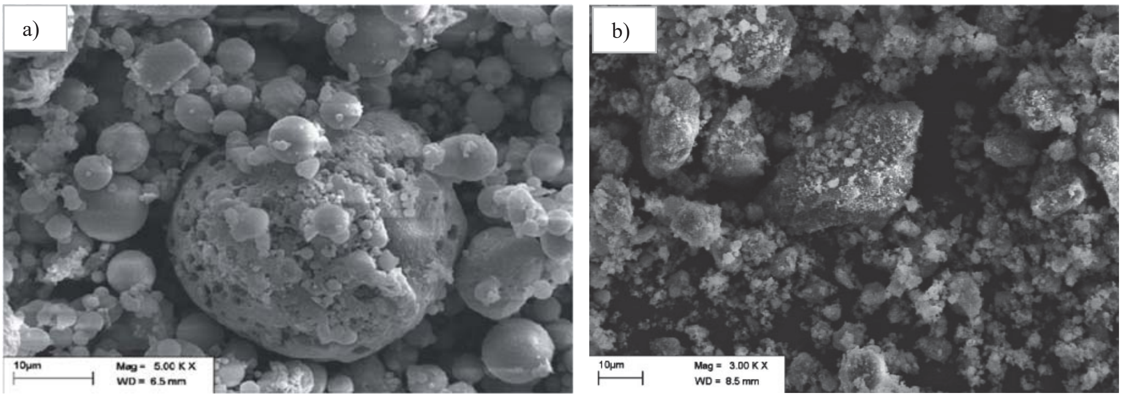

Fig. 1 Different grain morphology of (a) high-temperature fly ash and (b) fluidised fly ash

The possibilities of using fluidised fly ash are currently limited. The formation of the expansion product -ettringite-creates a major problem with their use. The fly ash is presently being used in soil stabilisation, where the influence of the expansion is negligible. The aim of many of the researchers is using safely this energy product as a full-fledged raw material for production of building materials like of concrete. Potential utilisation of this raw material is also in compliance with standard ČSN 72 2080 Fly ash and ash from fluidised bed combustion for building industry.

III. Methodology of the Experiment

The aim of this experiment is to find a suitable design methodology for the production of „Green concrete“ using both types of above-mentioned fly ash. In order to evaluate their positive and negative effects, the effect on the rheology of cement pastes on the development of hydration heat will be verified.

The next phase will verify their effects on the physico-mechanical properties of cement mortars at a horizon of 2 to 180 days. The following table shows the percentage of individual components. The high-temperature fly ash was from the production of thermal power plants burning black coal, and the fluidised bed combustion fly ash was from the production of a thermal power plant burning brown coal in the Czech Republic.

TABLE I
MIX COMPOSITION

Name	Cement [%]	High- temperature fly ash [%]	Fluidised bed combustion fly ash [%]
REF	100	-	-
C+P	55	45	-
C+P+50F	55	22,5	22,5
C+P+70F	55	13,5	31,5
C+P+90F	55	4,5	40,5
C+F	55	-	45,0

The water factor for each of the formulas was chosen to achieve the same degree of consistency as verified by the flow table test (EN 1015-3). The spillage value was set at 150 mm ± 5 mm. To achieve the same degree of consistency, it was necessary to increase the amount of mixing water with the increasing amount of fluidised bed combustion fly ash. This is related to the above-mentioned inappropriate morphology of fluidised fly ash grains. The increase in the water-cement ratio, depending on the amount of fluidised fly ash added, is shown in the following table. The designation of mixtures is based on their composition, C - cement, P – high-temperature fly ash, F – fluidised bed combustion fly ash. The number before the letter F indicates the replacement of the high-temperature fly ash with fluidised bed combustion fly ash in percentage.

TABLE II
PERCENTAGE INCREASE IN W/C

Name	**w/c ratio**
REF	-
C+P	**0 %**
C+P+50F	**+ 18,7 %**
C+P+70F	**+ 28,3 %**
C+P+90F	**+ 34,0 %**
C+F	**+ 39,6 %**

IV. MEASUREMENTS RESULTS

A. Rheology Testing

Viscosity measurement of cement pastes was performed using a ViskomatNT rotary viscometer. Measurement parameters were set to 90 minutes at 100 rpm.

The test vessel was placed in a cooling bath tempered at 20 °C. The mixing blade of the apparatus around which the container rotates was immersed in the vessel. The resistance of the mixture exerted against the blade was recorded as torque via software. The course of the measurement was recorded in the following graphical evaluation.

The graphical evaluation above shows that all prepared mixtures achieved almost identical rheological properties. In the case of the cement paste with the high-temperature fly ash, the viscosity of the mixture was slightly affected at the start, and, due to the appropriate fly ash grains morphology, a plasticising effect was achieved. An important finding of this measurement is that, when the correct water-cement ratio is set, it is possible to achieve almost identical rheological properties even when using a higher amount of fluidised bed combustion fly ash in the mixture.

Fig. 2 Rotary viscometer ViskomatNT

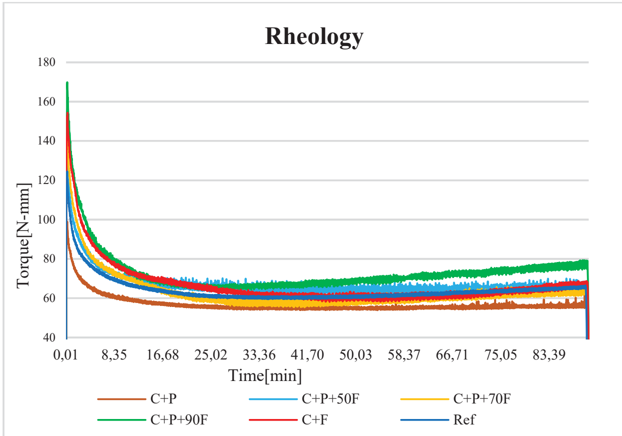

Fig. 3 Graphical evaluation of rheology measurements

B. Hydration Heat

The manifestation of contact of cement and water is its hydration, which is accompanied by the development of hydration heat. Hydration temperatures capture all reactions that release heat during solidification and hardening of the mixture. These reactions include, in particular, wetting, dissolving heat of major clinker minerals, precipitation and crystallisation as well as the formation of neoplasm in the mixture. The rate of hydration processes and their intensity were observed using this methodology. Determination of the hydration temperatures was performed by the semi-adiabatic method, according to EN 196-9.

To measure the hydration temperatures, the samples were once again prepared only from the cement pastes. The cement pastes were transferred to calorimeters placed in the air conditioning chamber during the measurement period to maintain constant ambient conditions. The air conditioning chamber was set at a temperature of 20 °C and a relative humidity of 50 %.

According to the graphical course of hydration temperature development, it is clear that the substitution of cement with both types of fly ash has a significant impact on the development of the hydration heat. The addition of fluidised bed combustion fly ash according to the course of hydration temperature causes a faster onset of hydration reactions, which in this case begin practically at the initial slaking of free lime in fluidised bed combustion fly ash. From the results of this measurement, it is clear that even the combination of the two types of ash has a positive effect on reducing the hydration temperature.

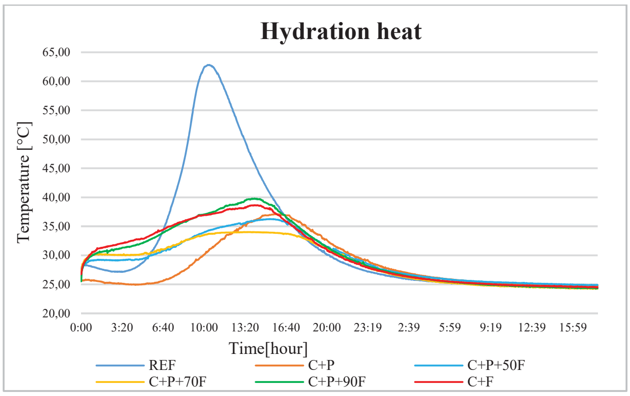

Fig. 4 Evaluation of hydration temperatures

C. Physico-Mechanical Properties

In the next phase of the experiment, cement mortars were prepared for the production of test specimens according to EN 196. Physico-mechanical properties were tested for 2 to 180 days on test bodies measuring 40x40x160 mm. The development of compressive strengths and tensile strength in bending was closely monitored. For the production of test bodies, the water-cement ratio values based on the previous part of the experiment were used.

Fig. 5 Testing compressive strength

A graphical comparison of the results of the individual strength characteristics demonstrated a significant decrease in fly ash concretes, especially in the initial strengths. This significant drop in compressive strength in particular begins to emerge with increasing maturation time, which is in direct line with the effect of the pozzolanic reaction. The attained strength parameters of the mixtures with fluidised bed combustion fly ash show its possible incorporation into the silicate composite similarly to classic high-temperature fly ash. If the design of the high-temperature fly ash composite is approached from the start with the view of its possible negative effects on the mixture, particularly on the consistency, it is possible to use, for the time being, the waste material to make the production of concrete even more economical and ecologically beneficial. If the negative effect of the fluidised bed combustion fly ash on the consistency of the mixture is eliminated by using suitable superplasticising agents and not only by increasing the water-cement ratio, its positive impact on the strength parameters can be expected to be even more pronounced.

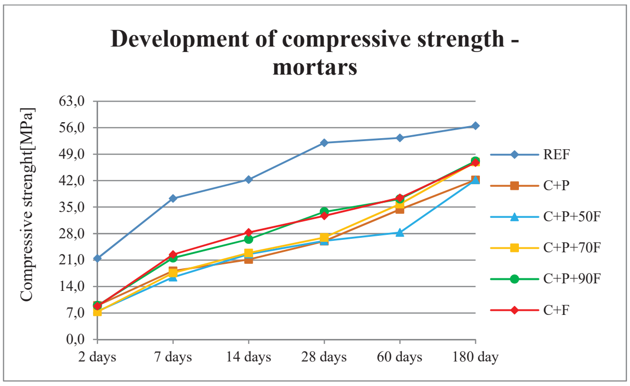

Fig. 6 Results of compressive strength testing

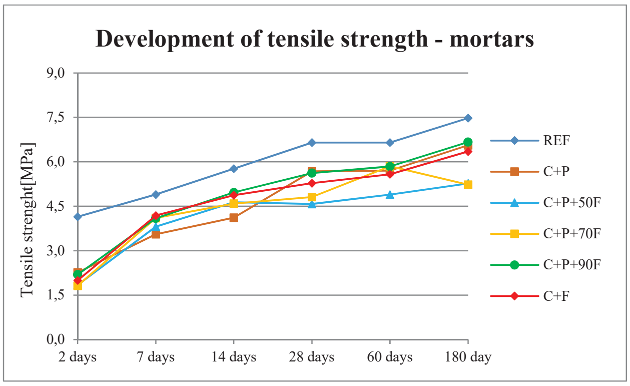

Fig. 7 Result of tensile strength after bending

V. Conclusion

The aim of this experiment was to investigate the possible uses of selected by-products created during the generation of electricity, especially fluidised bed combustion fly ash, which is still classified only as waste material. This experiment specifically researched the influence of fluidised fly ash on the rheology of the cement paste and the resulting physico-mechanical parameters of the composite. These characteristics were monitored over a longer time horizon, up to 180 days. According to this study, the selected fluidised bed combusted fly ash can be used for the production of cement composite in the correct technological process. Its impact, in particular, on the strength parameters is then more favourable than with the use of conventional high-temperature fly ash. An important role for the safe incorporation of the fluidised fly ash into the cement matrix will, however, will be in the technological process of preparing the mixture itself. It is especially important to deal with its significant negative impact on the consistency of cement paste. It has been shown that this can be overcome by increasing the water-cement ratio of the mixture. However, with a higher dose of fluidised fly ash, the increase in the water-cement ratio is quite pronounced, which could have a negative impact on the resulting strength and durability parameters of the composite. However, some previous studies have shown that this negative effect can also be dealt with by using a suitable superplasiticising agent [6]. A less-pronounced increase in the water-cement ratio would then most likely result in an even more positive influence on the strength characteristics of the fluidized fly ash over a longer time horizon.

When using the fluidised fly ash, there's often a question about altering the durability of the composite due to growing neoplasm with degradation effects, especially ettringite, within the microstructure of the composite. However, this fact has not been proven in this experiment. Even the samples with a high dose of fluidised fly ash showed a long maturing time, up to 180 days, and a continually increasing strength. It can therefore be assumed that the microstructure does not degrade the composite processes.

By seamless incorporation of the fluidised fly ash into the cement matrix, there is room for the possible use of the waste material, the production of which is still on the uprise.

Acknowledgment

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References

[1] Doležal, Jaroslav. *Jaderné a klasické elektrárny*. Praha: České vysoké učení technické v Praze, 2011. ISBN 978-80-01-04936-5.
[2] Stevens, W., Robl,T., Mahboub,K. The cementitious and pozzolanic properties of fluidized bed combustion fly ash. 2009 *World of Coal Ash (WOCA) Conference*, Lexington Ky, USA, 2009
[3] Ťažký, M.; Bodnárová, L.; HELA, R., Physico-mechanical properties of lightweight concrete with fluidized bed combustion fly ash based light weight aggregate, *Materials Science Forum*, ISSN 1662-9752, Trans Tech Publication, Switzerland, 2017
[4] Šulc, R, Formáček, P, Škvára, F., Peterová, A., Snop, R., Svoboda, P. Physical and mechanical characteristics of fly ash from coal burning. *Konference Popílky ve stavebnictví. ASVEP*, Brno, 2015. VUT v Brně, Fakulta stavební, ISBN 978-80-214-5192-6
[5] Škvára, F., Snop, R., Šulc, R., Zlámalová Cílová, Z., Peterová, A., Kopecký, L. Fluidní sulfátovápenatý popílek. *Konference Popílky ve stavebnictví. ASVEP*, Brno, 2015. VUT v Brně, Fakulta stavební, ISBN 978-80-214-5192-6
[6] Ťažký, M.; Hela, R., Elimination of negative influence of fluidized bed combustion fly ash on viscosity of cement mix, *Binders, Materials and Technologies in Modern Construction* II, ISSN 0255-5476, ISBN 9783038357407, Trans Tech Publication, Switzerland, 2016