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# UTILIZATION OF HIGH FLY ASH DOSAGE TO REDUCE CEMENT CONSUMPTION IN CONCRETE FORMULATIONS

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Abstract. The concrete production is responsible for high proportion of total carbon dioxide emission due to enormous consumption of Portland cement. This traditional binder system is due to high autogenous emission during calcination the main carrier of such negative environmental impact. The effective way to reduce the use of Portland cement is to replace that this binding material exhibiting lower energy demandingness. This paper deals with the utilization of fly ash as Portland cement replacement, which is frequently applied in concrete industry. The paper deals the highest replacement level in accordance with valid regulations. The experimental program was focused on the properties of fresh concrete mixture and basic physical and mechanical properties of hardened concrete. The attained results confirmed good potential of this approach, however the increase of plasticizer dosage was necessary to maintain a similar consistency of fresh mixture. That is why the fresh mixture exhibited lower level of air content.

Keywords: High dose of fly ash, compressive strength, consistency assurance, cement reduction.

## 1. Introduction

Currently, the industry research is mainly focused on cement production, as cement production is associated with a number of environmental impacts. These include the consumption of natural resources, environmental pollution, and especially $CO_2$ production, because cement production making up 4–8 % of total produced $CO_2$ emissions [1].

Our aim is therefore to develop sustainable concrete that has a lower carbon footprint and, in addition, uses secondary material from another industry that has no further use. One of the most common used alternative materials for these purposes is fly ash. This material is a by-product from burning pulverized coal in thermal power generating plants [2]. In recent years, fly ash production has been increasing steadily because a large number of countries depend on coal combustion. China is the largest consumer of coal and therefore the largest producer of fly ash, accounting for about half of the world's total production. Annual fly ash production reached 580 million tones and continued to grow [3]. Fly ash is a waste for thermal power plants that is further disposed of and can present a threat to the environment. Therefore, its further use to produce new materials is a necessary step forward.

Fly ash is a fine material of spherical particles with main chemical composition of $SiO_2$, $Al_2O_3$, $Fe_2O_3$ and CaO that participate in the hydration process by pozzolanic reaction with calcium hydroxide to form C-S-H gels [4]. These properties have attracted the focus of many research studies, which have focused on a variety of applications. Nassar et al. [5] reports in his work that 20 wt % replacement of cement with fly ash significantly improved long-term compressive strength, and in addition fly ash based concrete improved durability and abrasion resistance. On the other hand, Rashad et al. [6] focused on the effect of a high dose of fly ash (over 45 %) and concluded that such a high dose reduces heat production due to the hydration process, the high dose significantly reduces mechanical properties in a short age, the differences between normal concrete but decreases after a longer time, etc. Hemalatha et al. [7] add that most engineering applications in practice are around 30 MPa, and these strengths can be achieved even with a high proportion of fly ash.

This material has great potential for use in the production of ready-mixed concrete and therefore it was selected for the following experiment.

## 2. Experimental program

This experimental program was focused on the use of fly ash in concrete production to the maximum possible content. According to the national standard EN 206+A2 [8] the maximum amount of fly ash of 33 % of the cement content can be counted for the calculation of the water/cement ratio for the selected cement class CEM I. This maximum quantity was therefore used in the production of the test mixture. A reference mixture without fly ash was also monitored to evaluate the effect of fly ash dosage. Considering the experience gained from previous research [9], it was expected that the rheological properties of the fresh mixture would decrease, therefore plasticizing additives were used in the formulation design. In consideration of the high fly ash dosage, the additive dosage was increased. To demonstrate the effect of fly

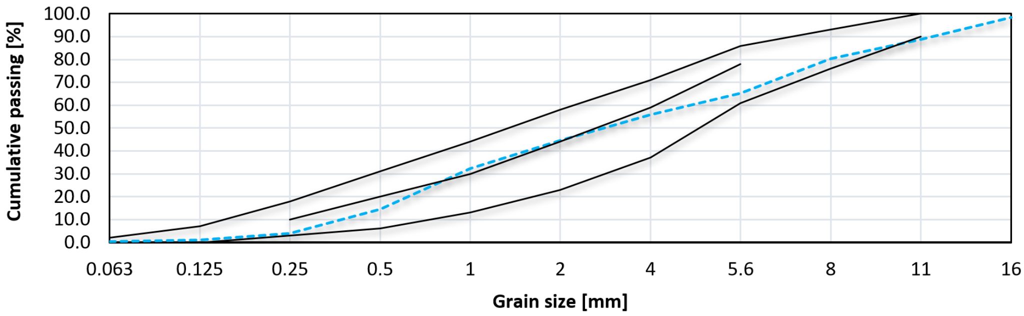


Figure 1. Grain size cure.

ash dosage, the properties in the fresh state and then in hardened state were monitored.

## 3. Materials

Cement class CEM I 42.5 R was used as a reference binder. This binder was subsequently replaced by fly ash in the ratio fly ash/cement = 0.33. This fly ash comes from the power plant Tušimice CZ. This fly ash was prepared by mixing different production fractions to meet the requirements of ČSN EN 450-1 [10] for fly ash category N. The chemical compositions of selected fly ash and cement is given in Table 1.

| | $Al_2O_3$ | $SiO_2$ | $K_2O$ | CaO | $TiO_2$ | $Fe_2O_3$ | MgO |
|---|---|---|---|---|---|---|---|
| Fly Ash | 33.9 | 49.8 | 1.7 | 1.8 | 1.2 | 8.9 | - |
| CEM I 42.5 | 5.3 | 18.7 | 0.8 | 63.0 | - | 3.1 | 2.6 |

Table 1. Chemical compositions of fly ash from power plant Tušimice CZ and cement CEM I 42.5 R.

The excavated aggregates were used of grain size 0/4 from the Dobříň locality, 4/8 and 8/16 from the Zbraslav locality. The specific dosage was determined with respect to the appropriate grain size curve of the mix. The resulting mixture grain size curve is given in Figure 1.

Plasticizing additive OST 1149 from STACHEMA CZ based on polycarboxylates was used to ensure the required consistency of fresh concrete and Microporan air-training admixture from the same manufacturer was used to achieve the required air content. The final composition of both monitored mixtures is given in Table 2.

| | REF $[kg\,m^{-3}]$ | EX1 $[kg\,m^{-3}]$ |
|---|---|---|
| CEM I 42.5 | 404 | 304 |
| Fly ash | 0 | 100 |
| 0/4 | 962 | 962 |
| 4/8 | 268 | 268 |
| 8/16 | 600 | 600 |
| Microporan | 0.55 | 0.55 |
| OST 1149 | 2.43 | 7.87 |
| Water | 163 | 155 |

Table 2. Composition of monitored mixtures.

## 4. Methods

The above quantity was converted to production volume and added to the laboratory mixer where the basic components were mixed. Next, the dosage of water and plasticizer was adjusted according to the desired consistency. After mixing, the fresh concrete was tested, and samples were made from the remaining concrete to determine the compressive strength.

The consistency was determined according to ČSN EN 12350-2 Testing fresh concrete: Slump-test [11]. In this test, a 300 mm high cone is gradually filled with concrete and compacted. After that, the cone is removed, and the settlement height of the fresh concrete is measured in relation to the original height. The result is the change in height in millimeters.

The air content of the fresh concrete was determined according to ČSN EN 12350-7 Testing fresh concrete: Air content [12]. In this method, the test container is filled with fresh concrete which is compacted. The container is closed and completely filled with water. A specific volume of air is then pressurized into the chamber, the pressurized air is then released into the fresh concrete, causing a decrease of pressure in the chamber and the resulting air content of the concrete is determined.

The samples 150 × 150 × 150 mm for compressive strength determination were stored in water after hardening until the time of testing. Specifically, the samples were tested at ages 2 and 28 days. This test was done according to ČSN EN 12390-3 Testing hardened concrete: Compressive strength of test specimens [13]. In this test, the specimens are loaded with pressure until they break. The resulting compressive strength is determined from the maximum measured load.

## 5. Result and discussions

Although efforts were made to dose the water and plasticizer to achieve the same consistency, the resulting consistency was not exactly the same. It is very difficult to set the same consistency in practice therefore, a slump classification according to EN 206+A2 [8] which uses classes S1-S5 (S5 shows the highest slump) was used. According to this classification, both mixtures reached the same class S4, which is in the range of 160 to 210 mm. The achieved consistency of the fresh concrete is shown in Figure 2.

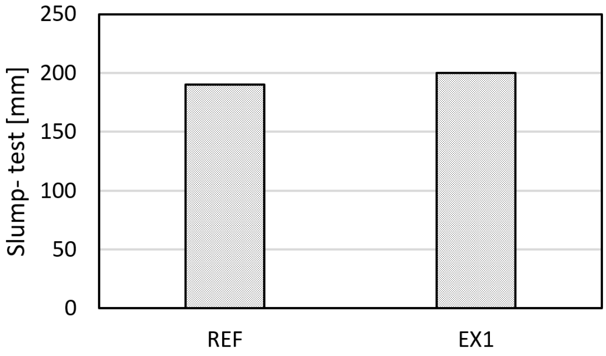


FIGURE 2. The consistency of the fresh concrete.

To achieve aeration of the concrete, aeration admixture was applied at a constant rate of 0.55 $kg\,m^{-3}$. This admixture apparently works effectively only in a mixture without fly ash, where an air content of 4.4 % was measured. The mixture with high fly ash dosage was not aerated using this admixture, as the resulting air content of the concrete was 2.6 %.

To achieve a higher air content, it would be necessary to either increase the dosage of this admixture or select an admixture designed specifically for this application. The resulting measured values are shown in Figure 3.

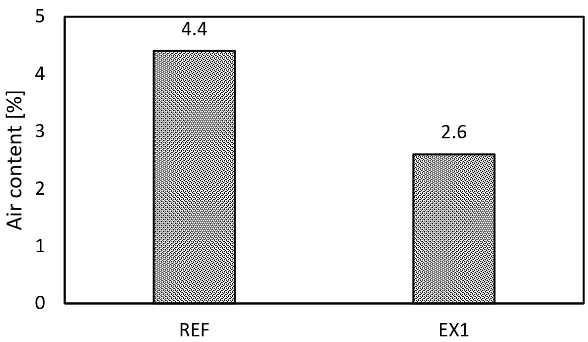


FIGURE 3. The air content of the fresh concrete.

As can be seen from the results, the reference mixture showed a higher increase in strength in the short term. At the age of 2 days, it showed a compressive strength of 34.7 MPa. This phenomenon is mainly due to the higher cement dosage in REF mixture and is consistent with the results of another research. Golewski [14] in his work states that the addition of fly ash at a rate of up to 30 % drastically reduces the compressive strength at early ages.

The mixture EX1 with high fly ash dosage already achieved comparable properties to the reference mixture in the long term (28 days). The fly ash contributes to the strength development by its pozzolanic reaction, which is generally showed at a higher age. At a higher age, the EX1 mixture would probably exceed the strength of the reference mixture. In general, it can be concluded that the concrete with a high fly ash content is comparable to the reference mix without fly ash at 28 days of age. The evaluation of concrete at 28 days is the most common in practice, and there are even concretes that are evaluated at 90 days; therefore, the lower strengths of concrete with fly ash at lower ages are not rated as unsatisfactory. The resulting strength was also influenced by the air content of the concrete. Due to the lower air content of the concrete with high fly ash content, very good strengths were achieved. With an identical air content of 4.4 %, the strength of EX1 concrete would probably have been lower. An overview of the achieved strengths is given in Figure 4.

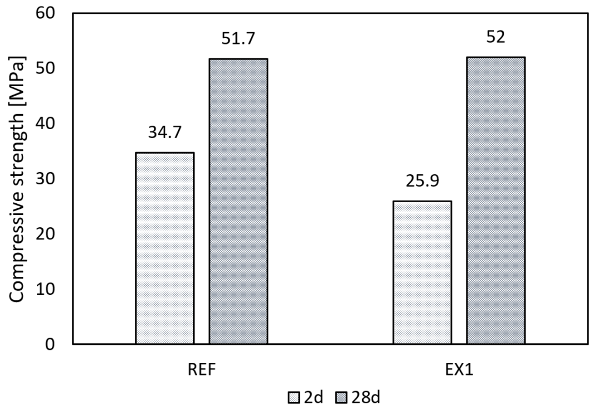


FIGURE 4. Compressive strengths of texted mixtures.

## 6. CONCLUSION

The purpose of this experiment was to verify the applicability of fly ash in the concrete recipes to the maximum possible extent allowed by the regulations at the place of use.

Despite the high dose of fly ash, a very good consistency was achieved while maintaining a similar dose of water. This result was achieved by increasing the dose of plasticizing additive. However, an appropriate dose is essential. Rafat Siddique [15] increased the dosage of plasticizing admixture in the concrete composition, even though the same consistency was not achieved. The increase in strength was slow in the first few days but the resulting compressive strength after 28 days was the same as the mixture without fly ash. In addition, a mix with a high proportion of fly ash is expected to achieve higher strengths at a later stage of age than a fly ash free mixture. This assumption is confirmed, for example, by the work of Charith Herath et al. [16]. They investigated, among other parameters, the strength development of concrete with a high proportion of fly ash at higher ages. Their research shows increase in compressive strength from 32.7 to 73.0 MPa over the period from 7 days to 450 days, respectively from 22.4 to 71.3 MPa based on the amount of used fly ash.

The air content was lower in the mixture with fly ash, which could be corrected by a higher dose of air-entrained admixture. Tarun R. Naik et al. [17] had to increase the dose of air-entrained admixture in his work to achieve comparable air content in mixtures with a high dose of fly ash. K. H. Pedersen et al. [18] noted that the combustion of other alternative fuels may also affect the fly ash quality, e.g. fly ash from coal/petroleum coke co-firing has shown a low air-entrained admixture adsorption capacity. This finding may ultimately lead to decision that some fly ash will be not able to be used for air-entrained concrete in practice.

From the initial tests achieved, fly ash was shown to be usable even at higher rates. This approach can reduce the amount of cement in the concrete while maintaining the basic properties. Verification of other properties such as shrinkage, creep, carbonation, etc. will be the subject of further research.

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