Paper sludge fly ash- From industrial wastes to new cementitious mixes

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Introduction

Paper sludge is a residue from the paper recycling process. In the past it consisted of unusable ingredients that needed to go to landfill sites or incineration plants. Nowadays, using an adjusted burning process with low emissions, fly ashes with good pozzolanic properties and without any hazardous contaminants are created. Within the Netherlands, there is the need to increase the knowledge about the utilization of paper-sludge fly ashes because of increasing landfill costs. So far the reuse of these materials in the concrete industry is minimal because of the increased water demand and content of free lime, which can reduce the properties of concrete.

Properties and treatment of the paper sludge fly ash

In this study, two fly ashes will be used as follows: paper sludge fly ash, termed “PsFA” and a commercial coal combustion fly ash (Class F) termed “R”. Table 1 presents the most important oxides in paper sludge fly ash, the coal combustion fly ash (R) and CEM I 42.5 N. It can be seen that the composition of PsFA is closer to the one of cement than to the one of the reference fly ash. The main difference is the high alumina content; otherwise, both CaO and SiO_2 contents are very close to the ones of CEM I 42.5 N. This is encouraging for the pozzolanic properties of the PsFA; however, the mineral phases which actually make up the paper sludge fly ash will define its binding properties. Generally, paper-sludge fly ash contains 23% CaO (calcium oxide as free lime, quicklime), 41% $CaCO_3$ (calcium carbonate) and 29% $Al_2O_3 \cdot 2SiO_2$ (metakaolin) as the main constituents. However, these can slightly vary because of the varying input from different factories. In concrete, these compounds have the following function: metakaolin is a reactive addition with pozzolanic properties; $CaCO_3$ has no or little pozzolanic properties and will only be used as a filler; CaO will absorb large amounts of water and therefore has a negative effect on the concrete because less water can react with cement. In normal cement mixtures the negative effect of reducing available water for the cement hydration makes it

application as cement replacement only suitable up to an amount of 10% with a small increase of the water cement ratio.

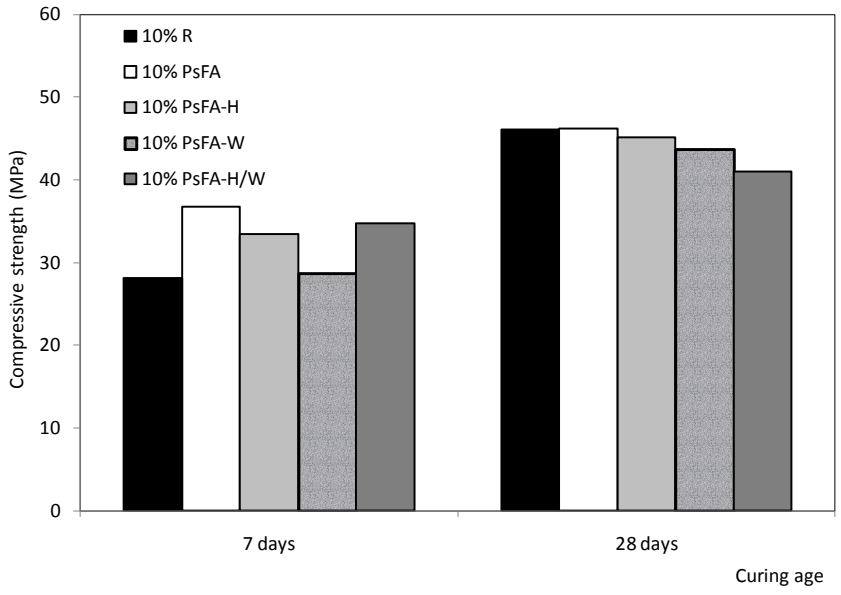
Table 1: Oxide composition of PsFA paper sludge fly ash, coal combustion fly ash R and CEM I 42.5N obtained by XRF

Oxide	PsFA (%)	R (%)	CEM I 42.5N (%)
MgO	2.0	1.9	1.6
Al_2O_3	15.0	22.3	5.8
SiO_2	22.0	55.0	18.8
SO_3	1.0	1.4	4.5
CaO	57.0	4.4	62.0
Fe_2O_3	0.7	8.4	3.6

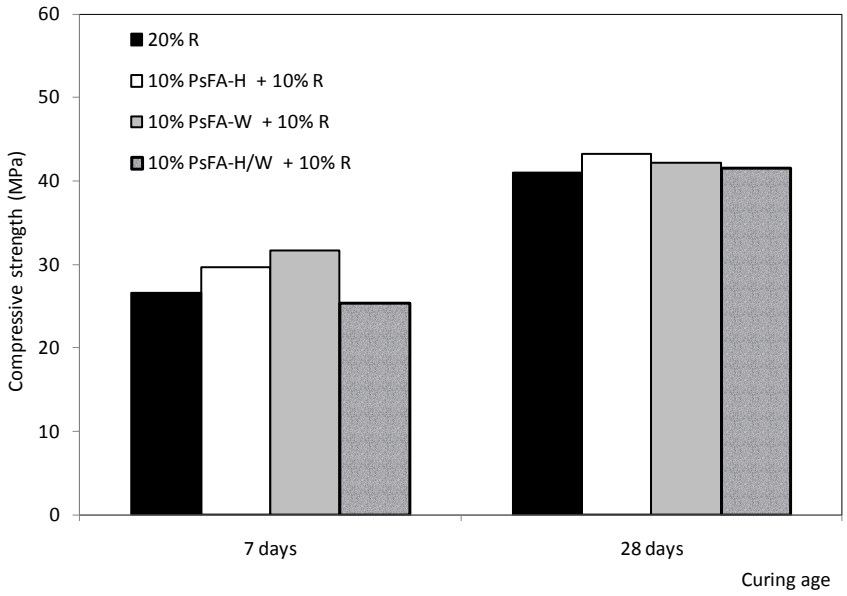
Two treatment routes are investigated in order to chemically upgrade paper sludge fly ash. The first one is to treat paper sludge fly ash with water to reduce the amount of free lime and at the same time increase the amount of portlandite that could be used to activate the pozzolanic reaction of metakaolin, or at least reduce the water demand of paper sludge fly ash. The final water-treated sample will be termed PsFA-W throughout this study. The second one is to thermally treat paper sludge fly ash to remove calcite by releasing carbon dioxide and therefore increase the concentration of free lime that later will be treated with water to increase the amount of portlandite. Besides the original PsFA sample and the water-treated one, two mare samples are now introduced: one thermally treated at 750 °C termed PSFA-H (heated) and one which is again water treated after heating, termed PsFA-H/W.

Mechanical properties

To investigate if, after different treatment steps, the compressive strength results of paper sludge fly ash is improved, standard mortars incorporating the original and the treated PsFA are made according to EN 196-1. Furthermore, the effect of paper sludge fly ash on coal combustion fly ash is investigated to see if the activation can be accelerated by the formation of portlandite. Results can be divided into two groups.



(a)



(b)

Figure 1: The compressive strength of PsFA-containing mortars after 7 and 28 days of curing; cement replacement of **(a)** 10% and **(b)** 20% by mass

The first group consist of 10% replacement of cement with the original and the three treated PsFA samples (termed PsFA 10%,PsFA-W 10%, PsFA-H 10% and PsFA-H/W 10%). The results are presented in Figure 1 (a). The second group consist of 10 % coal combustion fly ash R, plus 10% of each of the four PsFAs (termed PsFA-W 10% + R 10%, PsFA-H 10% + R 10% and PsFA-H/W 10% + R 10%) and the reference in which 20% of the cement is replaced by coal combustion fly ash (termed 20% R).
Figure 1(b) shows these mortar samples using 20% replacement of cement by mass. The same trend can be observed in both cases, with the mention that for 20% cement replacement all the PsFA samples perform better than the reference one in terms of 28 days compressive strengths, regardless of the applied treatment method.

Results and discussion

It is found that paper sludge fly ash has a positive effect on coal combustion fly ash and can by this increase its own utilization. Combining paper sludge fly ash with coal combustion fly ash increases the strength results for all obtained treatment methods, indicating that the paper sludge fly ash is a good alternative to replace 50% of coal combustion fly ash, increasing strength at 28 and even at 7 days by its activation properties. At first, samples containing 10% treated paper sludge fly ash (either thermal, water-or combined treatment) give lower strength results than the original paper sludge fly ash, indicating that the treatment of fly ash is so far not increasing its potential. However, combining paper sludge fly ash with coal combustion fly ash indeed increased the strength results for all obtained treatment methods, indicating that paper sludge fly ash is able to activate coal combustion fly ash.
The effect of the water treatment is clearly seen by the results obtained by thermally and water treated paper sludge fly ash (PsFA-H/W 10%) and the one with added 10% coal combustion fly ash (PsFA-H/W 10% + R 10%). Coal combustion fly ash decreased the water demand, making more water available for cement and paper sludge fly ash to hydrate. In this way, the strength results of PsFA-H/W 10% + R 10% are higher than without coal combustion fly ash, even though the cement content is 10% lower. Furthermore, the strength results with coal combustion fly ash are for each treatment higher than strength results obtained from PsFA 20% or 20% coal combustion fly ash (R 20%).