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Age-dependent trends in compressive strength of concrete incorporating fly ash

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Abstract. The research investigates the transformative potential of fly ash, an industrial byproduct, in enhancing concrete compressive strength and addressing environmental concerns associated with its disposal. The study employs a rich dataset from Mendeley Data, comprising 471 data points, to comprehensively explore the impact of fly ash on concrete strength at different ages. The analysis involves determining optimal compositions with fly ash, evaluating the fraction of cement replacement, and analyzing the generalized effect on compressive strength through graphical representation. Results reveal an inverse relationship between fly ash content and compressive strength, with nuanced patterns emerging at different curing ages. Despite the negative correlation, opportunities exist to optimize concrete formulations for specific strength requirements by judiciously incorporating fly ash. The weighted sum analysis identifies a composition with 33.6% replacement of binder by fly ash as optimal in the long term, showcasing the potential of this waste product as a valuable resource in sustainable concrete engineering.
Keywords: concrete, fly ash, compressive strength, curing age, weighted sum.

1. Introduction

The focus of concrete research has progressively shifted towards incorporating fly ash, a byproduct of combustion processes, into concrete mixtures [1]. Previously regarded as waste, fly ash has now gained significance not only for its ecological implications but also for its potential impact on concrete compressive strength [2].

The global construction industry, driven by a growing demand for concrete, has generated substantial amounts of industrial byproducts, including fly ash [3]. These byproducts, often dismissed as waste, hold untapped potential that researchers are eager to explore. Fly ash, with its pozzolanic properties, can significantly influence the mechanical and durability characteristics of concrete [4].

The problem at hand encompasses two aspects. Firstly, there is a pressing environmental concern related to the disposal of fly ash, which, if unaddressed, may lead to soil and water contamination [5]. Secondly, there is a compelling need to enhance the performance of concrete structures to meet modern construction demands [6]. The incorporation of fly ash into concrete formulations presents a unique opportunity to simultaneously address both challenges—transforming a potential environmental hazard into a valuable resource for the construction industry [7].

As we navigate this research landscape, our primary objective is to comprehensively investigate the impact of fly ash on the compressive strength of concrete at different ages. Concrete strength is a critical parameter directly influencing the structural integrity and longevity of buildings and infrastructure [8]. By understanding how the inclusion of fly ash affects this fundamental property, we contribute to academic discourse and offer practical insights that can reshape approaches to concrete engineering. Our exploration relies on Mendeley Data, a repository rich with diverse compositions and corresponding compressive strength data [9]. This dataset allows us to delve into the nuances of various concrete formulations, each with its unique blend of cementitious materials and fly ash content. The inclusion of data from different ages provides a dynamic perspective, enabling us to track the evolution of concrete strength over time in the presence of fly ash.

This research aims to unravel the intricate relationship between fly ash and concrete strength, utilizing a rich dataset sourced from Mendeley Data.

2. Methods

The data for analysis was retrieved from [9]. The data comprises 471 tabular data points related to the compressive strength of concrete for various ages of curing (from 1 to 365 days), encompassing data from compositions that include fly ash.

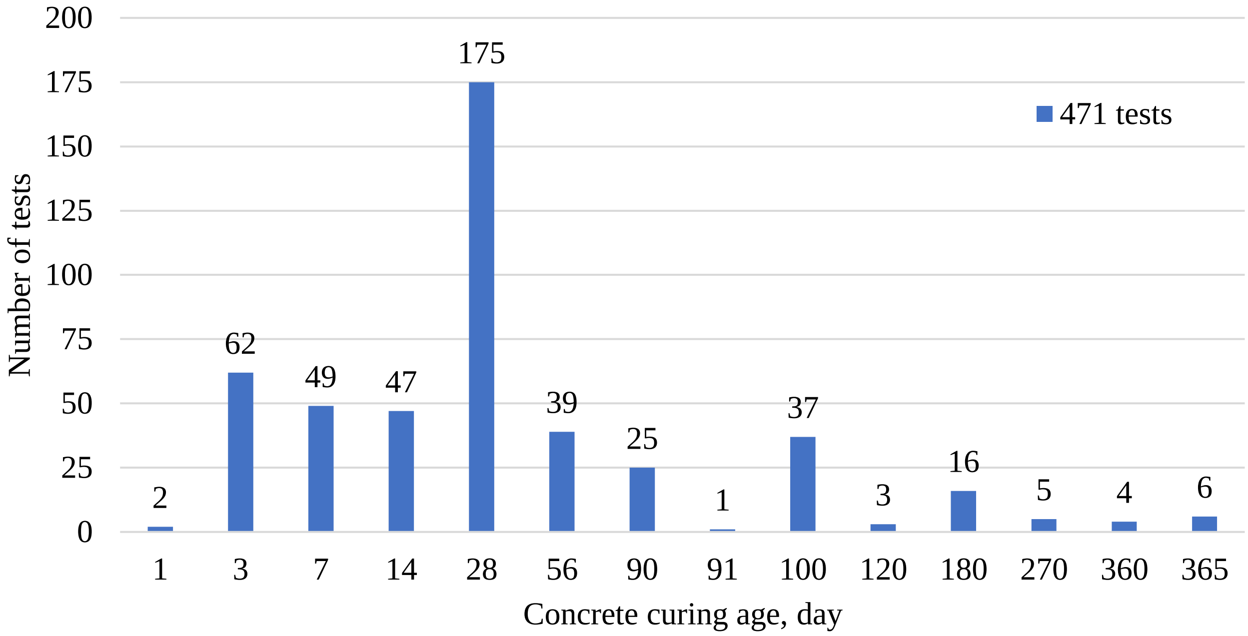

Figure 1 – Number of compression tests per concrete curing age [9]

The analysis was made in the following sequence:

1) Determining the number of compositions (including those containing fly ash) tested, by searching for rows with identical consumptions (in kg/m^3) of components (cement, fly ash, water, superplasticizer, coarse aggregate, fine aggregate).

2) Determining best compositions with fly ash in terms of compressive strength, by filtering tabular data per each testing age and defining the composition with the highest compressive strength value.

3) Determining the fraction of cement replacement with fly ash for the best compositions, by dividing its volume to the summed volume of cement and fly ash.

4) Analyzing the generalized effect of fly ash on the concrete compressive strength in different ages of curing, using graphical representation.

5) Defining the optimal composition with fly ash considering cumulative effect of fly ash consumption and compressive strength at the ages of 3 and 28 days, by weighted sum method [10].

3. Results and Discussion

Manipulation of the considered tabular data revealed that it presents results of compression tests of the 183 concrete compositions, including 95 containing fly ash. The compositions were tested at different curing ages, and those with fly ash were tested at the ages of 3, 14, 28, 56 and 100 days.

Table 1 below presents the list of best compositions of concrete utilizing fly ash that demonstrated highest compressive strength at one or several curing ages. Table also shows the fraction of fly ash in the binder combination.

Table 1 – Best compositions from [9]

Composition No.	Cement (kg/m^3)	Fly ash (kg/m^3)	Fraction of fly ash	Water (kg/m^3)	Superplasticizer (kg/m^3)	Coarse aggregate (kg/m^3)	Fine aggregate (kg/m^3)	Age* (day)	Concrete compressive strength (MPa)
1	246.83	125,08	33.6%	143.3	11.99	1086.8	800.89	3 14 28 56 100	23.52 42.22 52.5 60.32 66.42
2	275.07	121,35	30.6%	159.48	9.9	1053.6	777.5	3 14 28 56	23.8 38.77 51.33 56.85
3	252.31	98,75	28.1%	146.25	14.17	987.76	889.01	3 14 28 56 100	21.78 42.29 50.6 55.83 60.95
4	505	60	11%	195	0	1030	630	28	64.02

* For some curing ages there was not tests performed

From the table above seen that there is no composition demonstrating the highest compressive strength all at once considered curing ages. However, plotting the highest compressive strength values for each curing age, regardless of composition, on a graph (Figure 2) provides valuable insights into the influence of fly ash on compressive strength at different stages of curing.

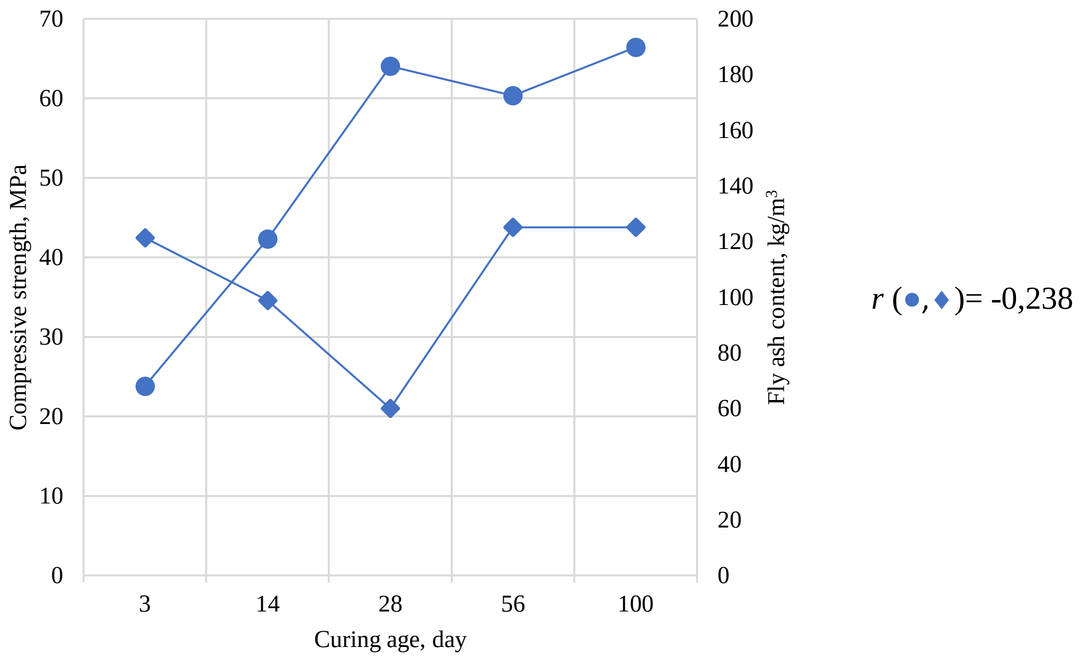

Figure 2 – Behavior of compressive strength vs. fly ash on different stages of concrete curing

The figure above shows the logical dynamics of compressive strength when the content of fly ash changes: the less the amount of fly ash the more the value of compressive strength. This denotes their inversely relationship, which is proven by the minor negative correlation factor *r* equal to -0,237 between these values. Despite this fact, there is still potential to select concrete compositions complying certain levels of compressive strength required saving a cement binder by replacing it partially by fly ash.

More thorough investigation of Table 1 above shows that it contains 3 or more values of concrete strength up to 56 days of curing, which helps to deduce certain patterns (Figure 3) for further analyzing the generalized effect of fly ash.

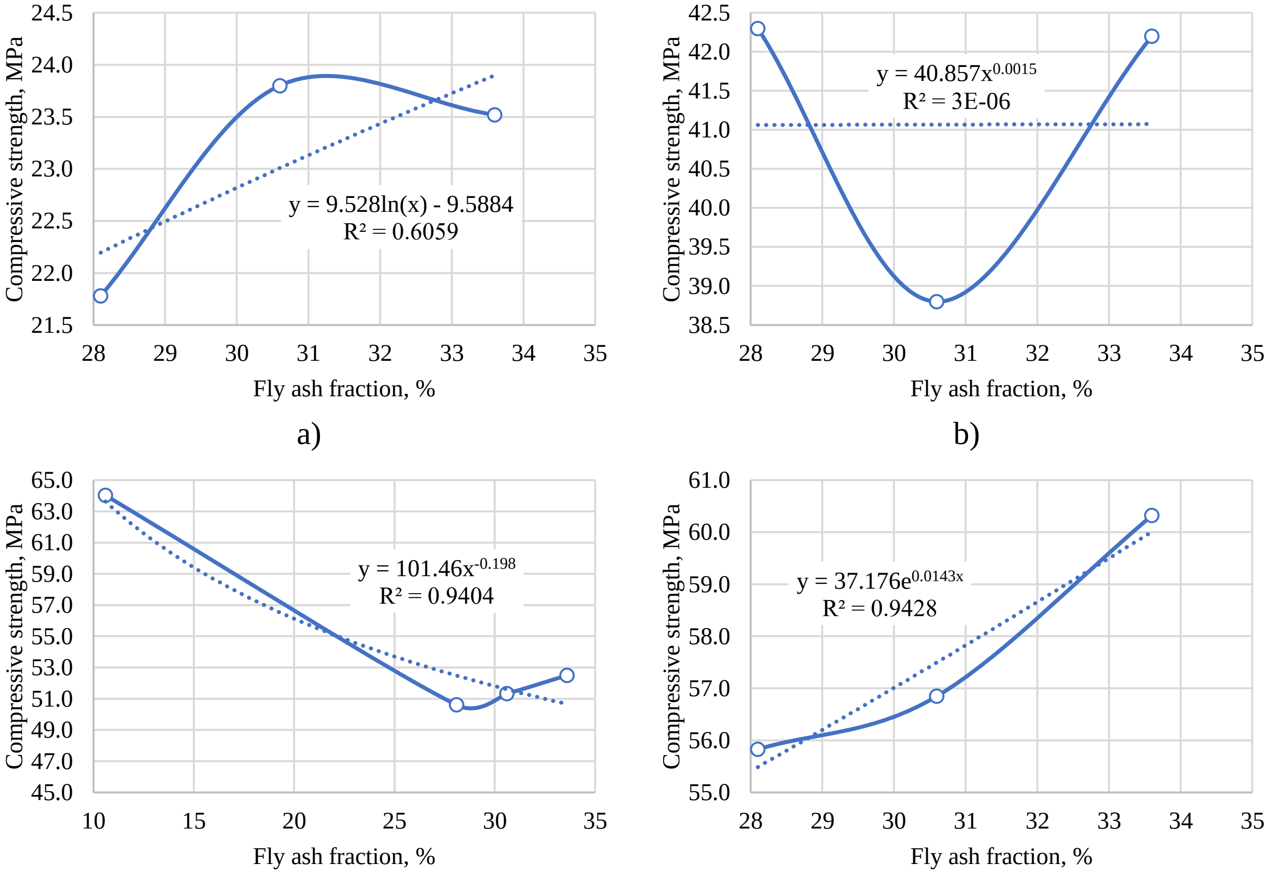

Figure 3 – Effect of fly ash on concrete strength for various curing ages: a) 3 days; b) 14 days; c) 28 days; d) 56 days.

From the figures above seen that increase in the fly ash fraction affects compressive strength variously, depending on the curing age. Thus, at the age of 3 days, an increase in the fly ash fraction to 31% led to the sharp increase in the compressive strength, but its further increase led to slight decrease of the compressive strength. The logarithmic function characterizing such pattern appeared best suiting. However, its coefficient of determination R^2 turned out to be a little weak, being equal to 0,6059, which makes that function inefficient for the considered period. At the age of 14 days, we can see even worse situation, where there is not much of a pattern. Further periods of concrete curing (28 and 56 days) showed notable patterns. Here, the increase in the fly ash fraction up to 28% had no positive effect on the compressive strength. But its further increase led to stable growth of the compressive strength.

The weighting (γ) of the values of such parameters of concrete compositions as fly ash fraction and compressive strength at the curing ages of 3 and 28 days and summing them showed the following noteworthy result (Figure 4).

Composition No.	γ_f	γ_3	γ_{28}	$\gamma_f + \gamma_3 + \gamma_{28}$
1	0.327	0.255	0.240	0.822
2	0.297	0.258	0.235	0.791
3	0.273	0.236	0.232	0.741
4	0.103	0.250	0.293	0.646
$\sum\gamma$	1	1	1	

Figure 4 – Weighted sum and ranking

As seen from the figure above, weight of the fraction of fly ash is arranged in descending order from the 1st to the 4th composition. However, it is not the case for the weights of the compressive strength at the age of 3 days, where the 2nd composition showed the highest weight. The highest weight of the compressive strength at the age of 28 days goes to the 4th composition. Cumulatively, the weighted sum suggests as the optimal composition No. 1.

4. Conclusions

1. The compressive strength of concrete exhibits an inverse relationship with the content of fly ash. A minor negative correlation factor (r = -0.237) validates the inverse relationship. Despite the inverse relationship, there remains the potential to optimize the concrete composition for specific compressive strength requirements by partially replacing cement binder with fly ash.

2. The influence of fly ash on compressive strength changes depending on the concrete's curing age. Initially, at 3 days, adding up to 30.6% fly ash enhances compressive strength, followed by a decrease with further increments. Although a logarithmic function captures this trend, its coefficient of determination ($R^2 = 0.6059$) is relatively weak. At 14 days, no clear trend is evident, but distinct patterns emerge at 28 and 56 days. Specifically, there's no enhancement in compressive strength with fly ash fractions up to 28.1%, but a consistent increase occurs with higher fractions.

3. The weighted sum analysis, cumulatively incorporating fly ash fraction and compressive strength at 3 and 28 days, designates composition with fly ash replacing 33.6% of cement binder as the optimal choice in the long term.

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