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# Mechanical properties of high-volume fly ash roller compacted concrete designed by maximum density method

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## HIGHLIGHTS

- ▶ Up to 60 wt% of cement, cement or aggregate was substituted with fly ash in RCC mixtures.
- ▶ Replacing cement with fly ash increased optimum water content of the mixture.
- ▶ Thus, reduced its strength even up to 180 days.
- ▶ Replacing aggregate with fly ash increased the compactibility of the mixture.
- ▶ W/b ratios of fly ash RCC were lower but their strengths were higher than control mix.

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## ABSTRACT

In order to study the effect of high volume fly ash on mechanical properties of roller compacted concrete, in addition to control mixture containing no fly ash, in two different series of mixtures cement or aggregate was partially replaced with fly ash. The maximum aggregate size was 25 mm in all of the mixtures which were designed using maximum density method. The cement content of the control mixture was 250 kg/m$^3$. In one series of the mixtures 20, 40 and 60 wt% of cement was replaced with fly ash. In another series, a part of aggregate (equal to 20, 40 and 60 wt% of cement) was replaced with fly ash. Totally 28 mixtures having four different water/binder ratios (0.30, 0.35, 0.4 and 0.45) were prepared. Among these, seven mixtures containing optimum water content were selected for further research. It was observed that in the mixtures where cement was substituted with fly ash, increasing the fly ash content caused reduction in compressive, splitting tensile and flexural strength values at all of the ages up to even 180 days. On the other hand, when aggregate was replaced with fly ash, increasing the fly ash content increased the strength values of the mixture at all ages compared to these of the control specimen.


## 1. Introduction

Concrete is to be designed to serve its intended purpose and become economical. Roller compacted concrete (RCC) is a special type of concrete which has recently attracted the attention from the whole world. This material is a no-slump concrete which is obtained by using similar materials to those of conventional concrete [1–5]. RCC mixtures can be designed using maximum density method or concrete approach [6,7]. RCC is preferred due to its cost efficiency, low heat of hydration, quick and easy application in concrete gravity dams, airport runways and highways coatings [8,9].

In RCC the amount of cement is usually between 100 and 200 kg/m$^3$, the water content varies from 100 kg/m$^3$ to 150 kg/m$^3$ and the air content is around 1–3%. However, in RCC larger coarse aggregate particles are used compared to conventional concrete. In RCC the maximum aggregate size ranges from 50 mm to 75 mm. The material prepared as a dry concrete is transported by dump trucks to the manufacturing laid in layers by grader or similar construction equipment and the compaction process is carried out by vibratory rollers. As transport, laying and compaction of RCC are very simple and practical it is much more economical than conventional concrete in terms of time and cost [4,10,11].

Various mineral admixtures such as fly ash are used in order to improve some mechanical and physical properties of concrete and to reduce its cost [12–16]. Fly ash is obtained as a waste product during the combustion of pulverized coal in thermal power plants. Fly ash is used as an admixture in cement and concrete because of its pozzolanic and/or self-cementitious nature [16–19].

The effect of fly ash on the mechanical properties of RCC mixtures was studied by several investigators. The influence of high amounts of fly ash used in roller compacted concrete on compressive and flexural strengths has been investigated by Cao et al. In this study 45–95 wt% of cement was replaced with fly ash in six

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different proportions. The cement content of the control mix was 300 kg/m$^3$. It was observed that there was a decrease in strength at early ages and an increase in strength at later ages while the amount of fly ash increased from 0% to 55%. Increase in the amount of fly ash from 55% to 95% in the mixture caused strength loss at both early and later ages [2].

Nipatsat and Tangtermsirikul studied the mixtures in which the total binder content was kept constant at 300 kg/m$^3$ and the amounts of fly ash were selected as 60, 120 and 180 kg/m$^3$. In these mixtures the water/binder ratios was kept as 0.41, 0.45 and 0.49, respectively. It is reported that an increase in both water to binder ratio and fly ash content result in a decrease in compressive, flexural and splitting tensile strengths at the ages of 7, 28 and 90 days [20].

Atiş et al. examined the effect of a non standard fly ash on compressive, flexural and splitting tensile strengths of RCC mixtures. In this study 15, 30 and 45 wt% by weight of cement was replaced with fly ash. It was emphasized that even 3-day strengths of fly ash RCCs were satisfactory, however, the mixtures containing 15% fly ash showed strength values close to or much higher than that of the control mixture only at the end of 28 days and this was the case at the end of 90 days in the mixtures containing 30% fly ash. The minimum strength at all ages was obtained in the mixture containing 45% fly ash [21].

In a study, conducted at Ege University, in the mixtures having cement content of 300 kg/m$^3$ 0, 20, 40 and 60 wt% of cement were replaced with fly ash. Increasing of cement replacement level from 20% to 60% decreased the 7, 28 and 90-day compressive strength values by 51%, 32%, and 34%, respectively [22].

Fly ash is used as a cement replacement material in several special types of concrete such as self-compacting reactive-powder concrete, and lightweight concrete [23–30]. Although some studies in the literature are available where fly ash is used as cement replacement in RCC, there is no study related with replacement of aggregate with fly ash in RCC mixtures.

In this study the 7, 28, 90 and 180-day compressive, flexural and splitting tensile strengths of high volume fly ash RCC mixture, where a part of either cement or aggregate was replaced with fly ash, were investigated.

## 2. Material and method

### 2.1. Material

In this study, a CEM I 42.5 R type cement conforming to EN 197-1 standard [31] a high-lime fly ash conforming to EN 450-1 standard were used [32]. The chemical composition, as well as some mechanical and physical properties of the cement and fly ash, obtained from their manufacturers, are given in Table 1.

The specific gravity and water absorption capacity of the aggregates used in the experiments were determined in accordance with EN 1097-6 standard [33]. The SSD specific gravities of 0–5 mm, 5–15 mm and 15–25 mm aggregate size fractions were obtained as 2.6, 2.65 and 2.67, respectively whereas the loose bulk densities of these size fractions were 1740, 1505 and 1480 kg/m$^3$, respectively.

The gradation of the combined aggregate obtained by mixing 60% 0–5 mm, 20% 5–15 mm and 20% 15–25 mm aggregate size fractions as well as standard gradation limits are shown in Fig. 1.

### 2.2. Method

The experimental study was performed in two stages:

(a) Determining the optimum water content of the mixtures: The optimum water contents of the control mixture and the RCCs containing fly ash partially substituted with cement and/or aggregate were determined. In this stage 28 different mixtures were prepared and among these, seven mixtures having optimum water content were selected for further studies.
(b) Determination of compressive, flexural and splitting tensile strengths: The 7, 28, 90 and 180-day strength values of the selected seven RCC mixtures were determined.

**Table 1**
Chemical composition, mechanical and physical properties of cement and fly ash.

| Chemical properties | | | Mechanical and physical properties | | | |
|---|---|---|---|---|---|---|
| Oxide (%) | Cement | Fly ash | Properties | | Cement | Fly ash |
| $SiO_2$ | 18.53 | 49.70 | Compressive strength (MPa) | 2 Day | 24.3 | – |
| $Al_2O_3$ | 5.01 | 17.01 | | 7 Day | 39.9 | – |
| $Fe_2O_3$ | 2.74 | 8.87 | | 28 Day | 47.0 | |
| CaO | 63.51 | 10.88 | Strength activity index (%) | 7 Day | – | 81 |
| MgO | 1.06 | 5.95 | | 28 Day | – | 87 |
| $Na_2O$ | 0.40 | 1.66 | Fineness | Blaine specific surface (cm$^2$/g) | 3880 | 4040 |
| $K_2O$ | 0.75 | 1.30 | | Residual of 0.090 mm sieve (%) | 1.0 | 5.3 |
| $SO_3$ | 3.14 | 2.52 | | Residual of 0.032 mm sieve (%) | 22.4 | 16.5 |

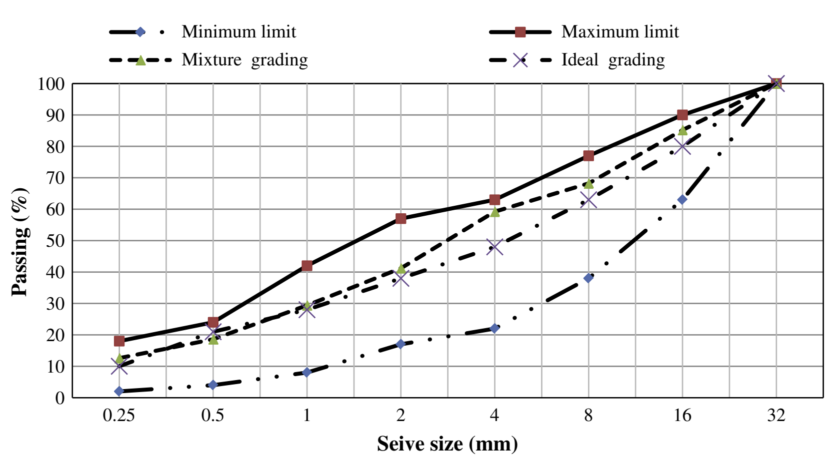


**Fig. 1.** Gradation curve of combined aggregate and TS 802 [34] standard limits.