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Properties of mortars with fly ash as fine aggregate

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HIGHLIGHTS

- We studied the influence of fly ash as fine aggregate in mortar properties.
- Fly ash decreases mechanical properties.
- Usage of fly ash as fine aggregate presents a new approach to consume high amount of fly ash.
- Usage of fly ash as fine aggregate in mortar increases strain capacity of mortar.

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ABSTRACT

Coal power plants produce million tons waste fly ash worldwide that cause environmental problem and threaten people health. Moreover, its depoting costs are high and need extensively large depot areas. Recycling is a strategy to consume waste content left from several industries. Although fly ash has been used in cement and concrete technology. In concrete technology it has been used as supplementary cementitious material or replacement material with a portion of cement until now. But, it has not been considered as fine aggregate. In this study, the effect of fly ash as fine aggregate in mortars is investigated. Flow ability, unit weight, ultrasound pulse velocity, compressive and flexural strengths, modulus of elasticity, stress–strain behavior and free drying and restrained shrinkage tests were conducted on mortars produced. It was observed that the usage of fly ash as fine aggregate presents a new approach to consume high amount of fly ash without causing significant changes on properties of mortars when it was used at the ratio of 60–70%.

1. Introduction

Environmental concern has increased worldwide. Countries have gotten conscience to environment and taken cautions to protect it since high contents of wastes have been produced. General tendency to decrease waste amounts from different industries is depoting them in large areas which results in huge and may waste deposits. To deal with this problem, many developed and developing countries have taken some regulations such as specifications, new rules, taxes, quota or limit to use natural resources and raw materials, etc. These regulations have prompted companies to give importance research and development (R&D). By this way, university-industry cooperation has improved and become strong to develop new materials and technologies. New products and technologies returns both economic income for company and country and reduce negative effect of waste materials on environment.

One of the sectors is construction technologies to evaluate wastes. Concrete, which is the most used construction material, has a high potentials recycling wastes in point of returning them to new and useful products or improving existing products. Many waste materials such as silica fume, demolished aggregates, waste tires, bottom ash, crush tile and brick, granulated furnace blast slag, ferrochromium slag, cupper slag, marble wastes, waste glass, polyethylene terephthalate (PET) bottle wastes, rice husk ash etc. has been evaluated in concrete.

Gencel et al. [1] produced interlocking paving blocks in which natural aggregates are partly replaced with waste marble. They observed that paving blocks produced with waste marble has enough strength for usage and increased freeze–thaw durability and wear resistance. So waste marble can be used as alternative for virgin aggregate in paving block production.

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Gencel et al. [2] used waste ferrochromium slag as replacement aggregate with natural limestone based aggregate in concrete. They reported that ferrochromium aggregates increase mechanical properties and wear resistance of concrete.

Uygunoglu et al. [3] used demolished concrete wastes to produce interlocking paving block. And they observed that paving blocks produced with these recylced aggregates had strength desired, 3.6 MPa. López Gayarre et al. [4] have produced concrete kerbs and floor blocks with recycled aggregates replacing two types of natural aggregates. They have concluded that the properties and manufacturing properties are little bit lower than those of the produced with only the natural aggregates. Another study of Lopez-Gavarre et al. [5] indicates the similar compressive strength of recycled aggregate concrete similar to the ones of ordinary concrete and they have found that the effect of curing conditions affect the compressive strength of recycled aggregate concretes likewise ordinary concrete.

Topcu and Bilir [6] used waste crushed tile as fine aggregate in mortar. They observed that there is no problem the usage of crushed tile up to the ratio of 60% replacement in point of mechanical strength since at this ratio compressive strength is above 20 MPa. Also, the usage of crushed tile reduces drying shrinkage and crack with due to it.

Li and Zhao [7] evaluated granulated blast furnace slag in concrete. And they observed that concrete with granulated blast furnace slag has early and long term compressive strengths and resistance to chemical attach and corrosion.

Park et al. [8] used waste glass as aggregate in concrete since recycling it as aggregate can be useful in point of conservation environment and economical advantage. They obtained compressive strength over 30 MPa when waste glass was used at 70% replacement ratio.

Eldin and Senouci [9] conducted experimental studies to investigate usability of waste tires as aggregate in cement based concrete. They observed that although the usage of waste tires with different sizes and contents as aggregate in concrete decrease compressive strength, concrete with waste tire aggregates did not show brittle failure, and had energy absorption capacity under loads.

Singh and Siddique [10] conducted a study on incorporation of bottom ash as replacement fine aggregate up to 100% for natural sand in concrete. Compressive strength of concrete containing 100% bottom ash instead of natural sand has no strength loss when compared with that of conventional concrete. But, bottom ash used as fine aggregate increases water demand to obtain workability desired. The usage of water reducer admixture compensates it.

Anwar et al. [11] produced concrete with rice husk ash at different ratios up to 40% of cement content and investigated characteristics of concrete produced. They observed that rice husk ash is a very active pozzolanic material and its usage in concrete increases mechanical strength even at early ages, durability such as chloride ions impermeability and decreasing permeability.

As understood a literature survey above, concrete technology has a capacity of consume wastes incorporating them useful products, and also has environmental advantages pretty significant in point of sustainability of natural resources since no natural resources have limitless reserves.

Another waste material is fly ash. Fly ash, a by-product of coal power plants, causes environmental pollution and its storage cost is pretty high. Turkey produces about 18 million tons waste fly ash per year [12]. It is about 80 million tons per year in India [13]. Overall fly ash content worldwide is about 600 million tons [14].

There are many papers published about the usage of fly ash in cement and concrete technology [15]. Fly ash is considered effectively as a supplementary cementitious material or replacement material with a portion of cement up to 30–40%. But, fly ash has not been considered as an aggregate in mortar and concrete until now. Aggregates occupy high volume about 75–80 wt.% of concrete. Thus, aggregates significantly influence the performance of concrete [2]. In this respect, the usage of FA as aggregate in concrete and mortar presents a new approach to consume high amount of FA.

In this study, the evaluation of fly ash as fine aggregate in mortar is investigated. Thus, flow ability, unit weight, ultrasound pulse velocity, compressive and flexural strengths, modulus of elasticity, free and restrained drying shrinkage tests are conducted on mortars produced.

2. Materials and method

CEM II/B-M 32.5 cement was used as hydraulic binder complying with TS EN 197-1 [16]. Cement was obtained from Set cement factory in Eskisehir, Turkey. Chemical composition of cement is presented in Table 1. The specific gravity, specific surface area, flexural and compressive strengths were determined corresponding to TS EN 196-1 [17]. Specific gravity and specific surface of cement used were 2.85 g/cm^3 and 3574 cm^2/g. Compressive strengths of cement at 2, 7 and 28 days were 12.8, 26.9 and 39.5 MPa, respectively.

Modified polycarboxylate based high-rate water-reducing superplasticizer (SP) was used to avoid the possibility of increase in water demand of mortars and to provide a satisfactory workability. Its density at 20 °C is 1.08–1.1 g/cm^3. Its pH and solid content are 5.7% and 40%. Standard sand (SS) (Rilem-Cembreu) with high silica content was used as reference sand to produce mortar. The sizes of SS grains remain below 2 mm.

The FA fine aggregate was provided from Catalagzı Thermal Power Plant in Zonguldak, Turkey. FA fine aggregate was used to replace standard sand (SS). Physical and chemical properties of FA are given in Table 2. The FA was used according to ASTM C 618 [18]. The FA is classified as class C and class F according to ASTM C 618. The sum of $SiO_2 + Al_2O_3 + Fe_2O_3$ must be more than 50% for class C and 70% for class F. FA was classified as F type according to the code because total of major oxides in FA is 89.59%. The SS is coarser than the FA. About 82% of FA grains are below the size of 200 μm. 49% of FA grains are below 2 mm. Approximately 1% of FA grains are finer than 0.08 mm and these finer particles may lead to increment in water demand. However, round shape of FA grains and usage of superplasticizer have decreased it. In this study, FA has replaced with the standard sand by weight.

Mixture proportioning was based on the absolute volume method. Six mortars with 40 × 40 × 160 mm size from each mixture were prepared with Portland cement as binder, standard sand, superplasticizer and fly ash as aggregate. The FA was replaced with the SS at different concentrations (10–100 wt.% at 10% intervals). The mix proportions of series are given in Table 3. After keeping demolded mortar specimens at 20 °C and 90% relative humidity for 24 h. specimens were immersed into water with 23 ± 2 °C for 7 and 28 days. On fresh mortars, flow table test was done to determine the effect of the FA on workability according to ASTM C 1437 [19]. Compressive and flexural strength tests were done according to ASTM C 349 [20] and ASTM C 348 [21]. The modulus of elasticity was determined according to ASTM C 469 [22]. Stress and strain values were calculated using force, shortening and dimensions of specimen. The σ–ε curves were plotted using the calculated values. Modulus of elasticity was calculated by the curves and the initial tangent method. Ultrasonic pulse velocity was determined according to ASTM C 597 [23]. Unit weight of hardened mortar was determined according to Archimedes principle. Free drying shrinkage was determined by measuring the lengths changes according to ASTM C 157 [24] on specimen with 25 × 25 × 285 mm.

The restrained drying shrinkage crack formation is provided by attempting ring test. Three ring type mortar specimens were produced for measuring the restrained drying shrinkage crack widths. After 24 h, the outer steel ring molds of specimens were removed. Specimens were subjected to drying at 23 ± 2 °C and 50 ± 4% relative humidity. Crack developments were observed and measured every day during 60 days. Crack widths were measured using an optical crack microscope every day. Ring specimens were exposed to drying conditions from only the outer circular surface of mortar. Top surface was sealed with silicone. So, internal stresses

Table 1
Chemical composition of cement (wt.%).

SiO_2	31.53
Al_2O_3	7.06
Fe_2O_3	3.29
CaO	48.89
MgO	1.46
SO_3	2.01
Free Cl^-	0.27
Loss on ignition	4.55

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