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Using of Pulverized Fuel Ash as a Solid Waste Material to Produce Aggregate and Concrete

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Abstract:

In this research, an ideal concept was applied in order to contribute to the efforts of resolving waste harm problems in our civilization. Recycling of municipal solid waste considered as one of the engineering technique which can be applied to eliminate discharges to the environment and reduce toxicity. Concrete technology can propose some strategies for recycling municipal solid wastes; such as using of fly ash (FA) in concrete production. In this study, artificial aggregates were used to produce high performance concretes. An energy saving process namely cold-bonded was applied for preparing artificial aggregate from a dry mixture of FA and Portland cement. A part of synthetic FA aggregate was improved by utilizing of soluble solution of sodium silicates. The type of high performance concrete in this study is self-compacting concrete (SCC) which was made with different water to binder (w/b) ratios. Fresh and transport properties as well as compressive strength of SCC were investigated. The results revealed that the improvement of artificial FA aggregate significantly affected the properties of SCC. The compressive strength at 28 day of SCC was found to be 30 MPa to 73 MPa at 28 days. Moreover, the experimented results was graphically analyzed and correlated for better understanding.

Key words: Cold-bonded, Fly ash, Self-compacting concrete

1. Introduction

Material has a pozzolanic activity due to the presence of SiO_2 and/ or SiO_2 and Al_2O_3 is commonly known as a pozzolan. It possesses little or no cementititous property, for this reason such materials can be classified as a pozzolanic or as a self-cementitious and pozzolanic material. Fly ash (FA) also known pulverized fuel ash is the best known, and one of the most commonly used pozzolans in the world. It is created in coal-fired electric power plants by burning process of pulverized coal. The amount of FA was increasing day by day worldwide due to the growth of thermal power stations and factories [1-4]. There are several advantages of utilization of FA in concrete industry. The use of FA in the construction sectors reduces the cost of FA disposal, efficient land use; protect soil from FA toxicity, and an equivalent decrease in CO_2 emissions associated with a reduction in production of Portland cement. However, one of most environmental advantages resulted from FA utilization in concrete production refers to the decrease of fly ash disposal in landfills. Landfill area is a big matter particularly in countries with limited dry-land space [5].

Artificial aggregate are utilized in several application like concrete, bricks and water filtration process. In spite of their origin, different raw materials can be used to produce artificial aggregate, i.e. industrial by-product materials such as sewage sludge, waste glass, FA, etc. or natural raw materials like clay [6]. The use of self-compacting concrete (SCC) in the actual structure has progressively expanded over the world in the recent years and presents successful alternative to

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conventional concrete. Generally SCC incorporates mineral and chemical admixtures to enhance concrete quality. For example, FA can be used as a mineral admixture to enhance the performance of SCC in terms of quality (flowability and permeability) and reduce the amount of cement (saving cost) [7].

In this experimental study, combined powder mixture of 90% FA and 10% cement was used through the cold bonding process to produce artificial FA aggregate. Half of coarse aggregate particles were treated with water glass to prepare two different types of aggregate; natural surface aggregate and treated surface aggregate. Each aggregate type was incorporated in the design of three different SCC mixtures having 0.25, 0.37, and 0.50 w/b ratios. To attain the purposes of this study, several tests were carried out to evaluate the fresh, permeability, and compressive strength. For another step forward, relationships between the evaluated properties were obtained.

2. Materials and Method

In this investigation CEM-I 42.5 ordinary Portland cement and FA class F were utilized in concrete and artificial aggregate production. FA provided from thermal power plant founded in Çatalağzı in Turkey and utilized instead of a specific weight of 25% cement in all concrete mixtures. Table 1 presents the physical and chemical properties of the cement and FA.

Based on polycarboxylic-ether formulation high range water reducing admixture (HRWRA) was used in all mixes to attain the required flowability for fresh concrete. The commercial name of HRWRA is Glenium 51 supplied in a plastic sealed container as a dark brown liquid and had a specific gravity of 1.07.

A combination dry mixture of 90% FA and 10% cement by weight was agglomerated at room temperature through moistening at a rotation of 42 rpm and in a 45 degree angle tilted pan. As soon as the pelletization process had completed, the fresh pellets were self-cured in plastic sealed bags at normal condition of 20 ^{o}C and 70% relative humidity for 28 days. Figure 1 shows the main production stages of artificial aggregate through cold-bonded process. The produced aggregates were sieved into coarse fractions of 4-16 mm and fine fractions of 4-2 mm. The coarse FA aggregate was divided into two groups; the first one was kept in its natural surface condition whilst the second was treated by water glass solution. The specific gravity of natural and treated surface aggregate was 1.75 and 1.76, respectively, whereas it's about 1.74 for fine artificial aggregate.

On the other hand, crushed sand was used as a normal weight aggregate. The crushed sand was sieved into size fractions of 0.25-2 mm. The specific gravity was 2.4.

A total of 6 SCC mixtures were designed at three different w/b ratios of 0.25, 0.37 and 0.50, with total binder contents of 600 kg/m^3, 550 kg/m^3 and 450 kg/m^3, respectively. The total volume of aggregates in all SCC mixtures was covered by 50% artificial coarse aggregates, 25% fine artificial aggregates, and 25% crushed sand. The gradation curve of coarse and fine aggregate mixture is presented in Fig. 2. The actual mixture proportions are tabulated in Table 2, in which the mixes were designated according to w/b ratio followed by the type of artificial FA aggregate. For example, the mix "0.25-AFA" indicates concrete made with w/b ratio of 0.25 and untreated artificial FA aggregates, whereas “0.25-AFA-T” represents the concretes made with treated artificial fly ash aggregates at 0.25 w/b ratio.

Table 1. Properties of cement and FA

Analysis Report	Portland Cement	FA
CaO (%)	62.12	2.24
SiO_2 (%)	19.69	57.2
Al_2O_3 (%)	5.16	24.4
Fe_2O_3 (%)	2.88	7.1
MgO (%)	1.17	2.4
SO_3 (%)	2.63	0.29
K_2O (%)	0.88	3.37
Na_2O (%)	0.17	0.38
Loss of ignition (%)	2.99	1.52
Specific gravity	3.15	2.04
Blaine fineness (m^2/kg)	394	379

Table 2. Details of mix proportions in kg/m3

Mix ID	Cement	Fly ash	Water	AFA (4-16) mm	AFA (2-4) mm	Natural aggregate (0-2) mm	Fresh density
0.25-AFA	450	150	150	551.7	273.9	375.9	1959.4
0.25-AFA-T	450	150	150	554.8	273.9	375.9	1962.5
0.37-AFA	412.5	137.5	203.5	520.1	258.3	354.4	1889.7
0.37-AFA-T	412.5	137.5	203.5	523.1	258.3	354.4	1892.7
0.50-AFA	337.5	112.5	225	531.9	264.1	362.4	1835.4
0.50-AFA-T	337.5	112.5	225	534.9	264.1	362.4	1838.4

Figure 1. Production of artificial FA aggregate

2.1. Test procedure

Several tests were carried out in this investigation in order to evaluate the fresh, permeability, and compressive strength of SCC. Slump flow, $T_{500\ mm}$ slump flow time, V-funnel, and L-box height ratio tests were used to investigate the fresh properties of SCC in accordance to EFNARC [8]. Different classes of fresh concrete with respect to application areas can be found in EFNARC recommendations. Figure 3 shows some examples about tests of workability of fresh concrete.

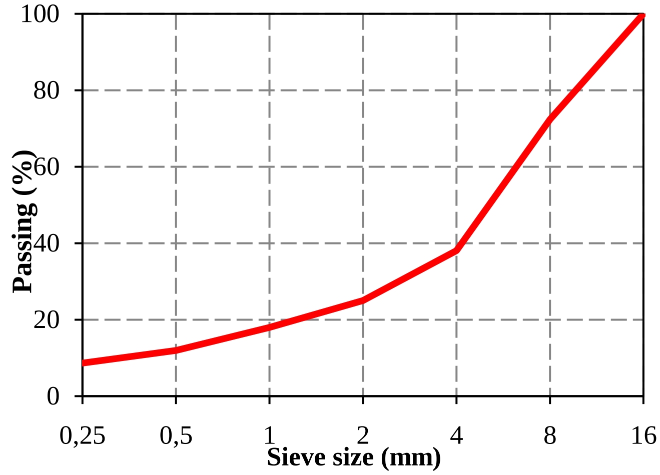
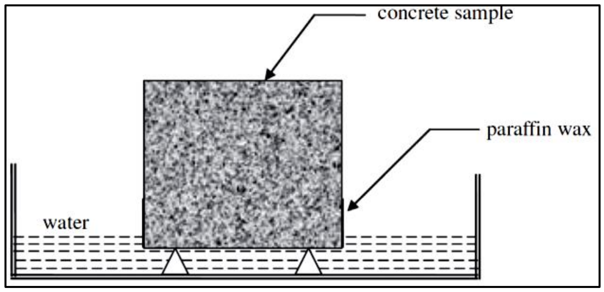


Figure 2. Gradation curve of aggregate

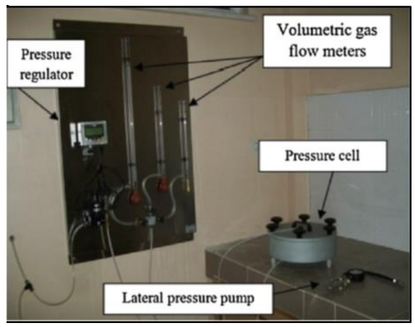
Hardened properties were studied in the term of water sorptivity, gas permeability, and compressive strength. As per to ASTM C1585 [9], three 100 mm cubes for each SCC mixture were used to calculate the average of water sorptivity at 28 days. The CEMBUREAU method given by RILEM TC 116 [10] was employed to evaluate gas permeability of SCC mixtures at 28 days. Figure 4 depicts water sorptivity test set up and gas permeability apparatus. Compressive strength test was conducted on water cured samples of 150x150x150 mm by means of a 3000 kN capacity testing machine at 28 days of age. Three cubes were tested and the average values were reported for each type of SCC mixture.

(a) (b) (c)

Figure 3. (a) Slump flow test, (b) Measurement of V-funnel flow time, (c) L-box apparatus and test procedure



a)



b)

Figure 4. (a) Water sorptivity test set up, (b) Gas permeability apparatus

3. Results

Table 3 and 4 presented the results of fresh and hardened properties of SCC made with natural surface aggregate and treated surface aggregate, respectively. Additionally, the correlation between V-funnel flow time and slump flow time, gas permeability coefficient and compressive strength, water sorptivity index and compressive strength are represented in Fig. 5 to 7, respectively.

Table 3. Results of fresh concrete tests of different SCC mixtures

Mixture	Slump flow diameter (cm)	T_{500} slump flow time (s)	V-funnel flow time (s)	L-box height ratio
0.25-AFA	700	3.66	24.50	0.84
0.25-AFA-T	738	3.18	20.34	0.95
0.37-AFA	710	1.16	7.84	0.92
0.37-AFA-T	735	0.45	5.71	1.00
0.50-AFA	702.5	0.28	3.36	0.96
0.50-AFA-T	730	0.24	3.16	1.00

Table 4. Results of hardened properties of different SCC mixtures

Mixture	Water sorptivity index ($mm/min^{0.5}$)	Gas permeability coefficient ($10^{-16}xm^2$)	Compressive strength (MPa)
0.25-AFA	18.5	2.465	55.1
0.25-AFA-T	6.5	1.479	72.8
0.37-AFA	36.5	7.006	43.9
0.37-AFA-T	30	5.045	55.1
0.50-AFA	65	17.455	30.6
0.50-AFA-T	50.5	14.369	36.0

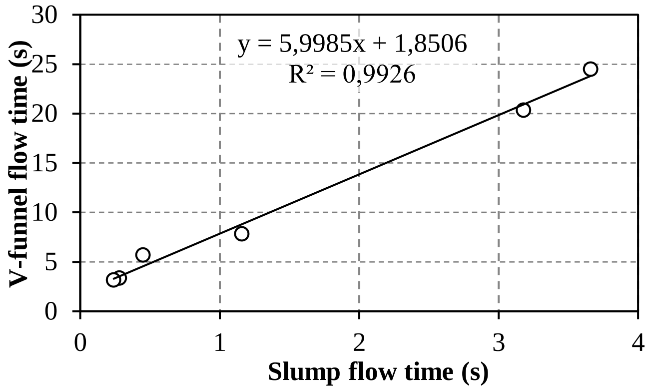


Figure 5. Relationship between slump flow time and V-funnel flow time

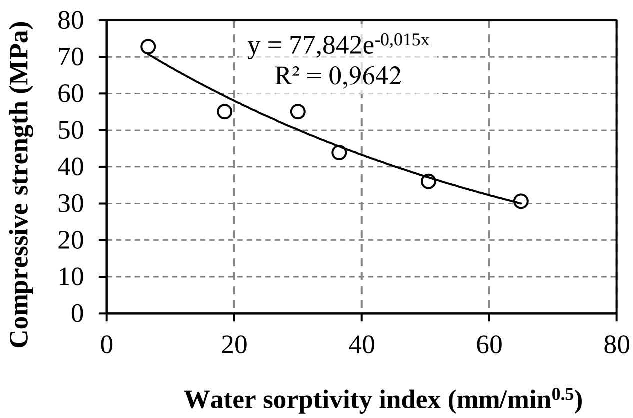


Figure 6. Relationship between slump flow time and V-funnel flow time

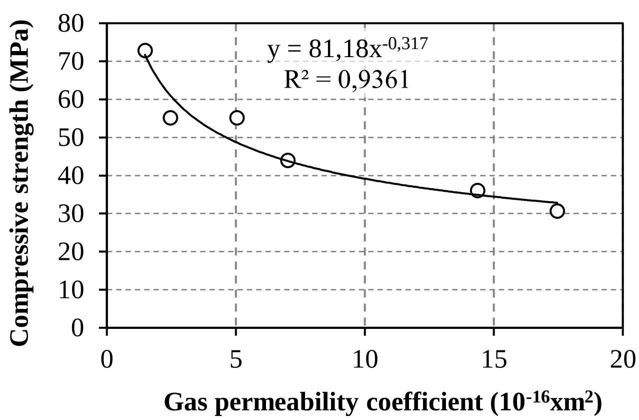


Figure 7. Relationship between gas permeability coefficient and compressive strength

4. Discussion

In this study the concretes were designed to give a slump flow diameters of 700 ± 50 mm. As presented above, Table 3 illustrates the results of tests used to evaluate fresh concrete properties. The slump flow diameters of SCC were determined in the range of 700-738 mm. According to the results, the use of high binder ratio of 600 kg/m^3, untreated surface aggregate, and lower w/b ratio of 0.25 in the mixture namely 0.25-AFA caused to achieve lowest diameter of 700 mm. On the other hand, the treatment technique which was performed to enhance aggregate quality caused to increase slump flow diameter of fresh concrete comparing to those made with natural surface aggregate regardless w/b ratio. This role may be attributed to the weaker cohesion between the cement mortar and surface treated aggregates due to the smooth and comparably impermeable surface of treated aggregates. Moreover, all SCC mixtures can be diagnosed as slump flow SF2 (class 2) with respect to EFNARC [6] limitations. Regarding the slump flow time and V-funnel flow time, the results presented in Table 3 showed that the flowability of fresh concrete decreases gradually with the increase of w/b ratio from 0.25 to 0.50. To affirm that a SCC has no blocking risk, height ratio must be not less than 0.8 [6]. Similar to slump test and V-funnel flow time, the height ratios of L-box apparatus are influenced by the use of different w/b ratio and aggregate type (treated or untreated). It can be seen that the test emphasized that the utilization of treated aggregate provided a systematic increase in the L-box height ratio. As clearly seen from Table 3, increasing of w/b ratio caused to increase H2/H1 ratio slightly. Moreover, typical height ratio was achieved for 0.37-AFA-T and 0.50-AFA-T mixes.

Water sorptivity of concrete are greatly influence by mixture proportions of concrete, age, aggregate properties, and volume of air voids [9]. As can be clearly seen in Table 4, water sorptivity index of 0.50-AFA and 0.50-AFA-T mixes decreased from 65 and 50.5 $mm/min^{0.5}$ to 18.5 and 6.5 $mm/min^{0.5}$ for those made with w/b ratio of 0.25, respectively. This is due to the w/b ratio is one of the most factor affected the pore structure intensification. The high porosity of natural surface aggregate comparing to treated surface aggregate caused to increase water transportation ability of SCC made with the former one. Similar behaviour was observed regarded gas permeability test. In this context, the minimum gas permeability was detected at 0.25-AFA-T at w/b ratio of 0.25 as 17.455×10^{-16} m^2, while the maximum was observed at 0.50-AFA as 17.455×10^{-16} m^2. Table 4 also shows the compressive strength of different SCC mixtures. It was determined that there was a remarkable reduction in compressive strength of all SCC types due to the loss of products resulted through the hydration process induced from w/b ratio increasing. On the other hand, surface treated FA aggregate caused an increase in the compressive strength of SCC when compared with those implemented with untreated FA aggregate. This finding in agreement with the suggestion of Topçu and Uygunoğlu [11] who they reported that the high quality aggregates governing the increment in the strength of concretes.

In general slump flow test is widely used in sites than other tests to evaluate fresh properties. Thus, it is useful to establish a mathematical relation between them to be used for assessment purposes. It can be seen from Fig. 5 the correlation between slump and v-funnel induced with a high regression factor which reflects the perfect confidence for the liner relation that presented in the same figure. Figure 6 and 7 present the correlation between water sorptivity index and gas permeability coefficient with compressive strength, respectively. Figure 6 revealed that the best correlation between water sorptivity and compressive strength was performed by an exponential curve fitting whilst it's a power curve fitting for the relation presented in Fig. 7 graphed between gas permeability and compressive strength.

Conclusions

The main conclusions of the study can be summarized as follows:

- The successful employment of pulverized fuel ash at concrete and aggregate production can be contributed to the effective efforts to organize cleaner world.
- High performance concrete can be produced by using FA as a supplementary cementitious material and as a raw material for artificial aggregate production.
- Cold-bonded process is an effective method can be easily used for aggregate production with lower energy consumption and number of labour.
- Production of artificial aggregate through cold-bonded process from 10% cement and 90% FA obtained aggregates having specific gravity lower than that of natural aggregate and can be used to produce lightweight concrete.
- Improving aggregate by water glass treatment significantly enhanced fresh and transportation properties of concrete as well as its compressive strength.
- Higher compressive strength of about 73 MPa and lower permeability (water sorptivity index of 6.5 $mm/min^{0.5}$ and Gas permeability coefficient of 1.479 10^{-16} x m^2 resulted in concretes having lower w/b ratio and treated FA aggregate.

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