Performance of concrete made with industrial incinerator ash as fine aggregate replacement

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Abstract: Concrete is one of the man-made materials that uses more than any materials in the structures. These days with increasing the use of concrete, the best way for replacement of natural aggregates is the use of urban and industrial wastes in concrete products. The reuse of this materials will be able to decrease the exploitation of natural mines and its one of the best way to reducing the end cost of projects. In this study the Incinerator Ash is uses as replacement of natural fine aggregates in concrete. These industrial aggregates substitution in the various percentages of natural sand and the mechanical and physical properties of concrete samples were determined. The unite weight of new samples were less than ordinary concrete, but the water absorption of this kind of concrete per different percentage of ash replacement has variable behavior. The compressive strength of new concrete was lower than ordinary one and to achieve the workability of natural specimen, extra water needs to be considered.

[Arash Dalili osgouei, Farshad Maleki, RaminVafaei Poursorkhabi, Ardalan Azardoust. **Performance of concrete made with industrial incinerator ash as fine aggregate replacement.** *J Am Sci* 2013;9(5s):74-78]. (ISSN: 1545-1003). http://www.jofamericanscience.org.

Keywords: light weight concrete, natural sand, Incinerator Ash, compressive strength, unite weight

1. Introduction

During recent years there has been a growing emphasis on the utilization of waste Materials and by-products in construction materials (Rafat, 2010).

Municipal solid waste ash (MSWA) is the by-product produced during the combustion of municipal solid waste. Incineration is the commonly used practice for managing the increasing production of municipal solid waste (MSW). The nature and quality of MSW ash depends greatly on the nature of the waste, type of combustion unit, and nature of the air-pollution-control device. Municipal solid waste combustor ash is a relatively lightweight material compared with natural sands and aggregate (Walter, 1976; Federal Highway Administration, 1997).

The chemical composition of three municipal solid waste incineration bottom ashes (MBA) exhibited the bottom ashes were mainly composed of Si, Al and Ca oxides, accounting for 79–82% of the material on a dry weight basis. In particular, the Si and Al oxides content ranged from 52 to 70% (Filipponi et al, 2003).

Various uses of MSW fly ash included: 1. construction materials; 2. geotechnical applications; 3. agriculture; and 4. miscellaneous applications. MSW fly ash could be used as partial replacement for cement in concrete mixes as a supplementary cementitious material as it contains some quantities of typical. Cement minerals, although in lesser quantity than cement clinker (Ferreira et al, 2003; Rebeiz and Mielich, 1995).

Hossam (2005) studied the properties of hot-mix asphalt concrete containing MSW incinerator ash with percentages up to 40%, by total aggregate weight. He recommended using up to 15% MSW ash replacement of the aggregate for bituminous surface course, Twenty percent of ash replacement can be used for bituminous base course and higher percentages of ash replacement should be avoided for surface or base course. Bertolini et al. (2004) showed that bottom ashes from MSW incineration are potentially attractive as mineral additions for the production of concrete. When MSWI bottom ashes were added to the concrete mix after being dry ground, strength and durability of concrete were negatively affected by entrapment of gas bubbles. Chen et al. (2010) reports the investigation on manufacturing lightweight aggregate by incorporating municipal solid waste (MSW) incineration fly ashes and reaction ashes with reservoir sediments. The results demonstrate that the aggregate thus fabricated is non-hazardous for construction use.

Hence in this study, the opportunities to use incinerator ash as aggregate replacement have been investigated and compared with control samples.

2. Materials and Methods

In order to investigate the mechanical properties of concrete that containing Incinerator Ash, specimens of a cube shape of 150×150×150 mm were fabricated. These specimens were different in the content and type of Ash particles as a portion of fine aggregates in concrete.

2.1. Materials

The materials used in this study are as follows:

Cement: Type I Portland cement (soufian cement factory) was used in all types of aggregate content mixtures.

Fine aggregate: The fine aggregate was natural sand of 4.75 mm maximum size obtained from Charm Shahr in the area of Tabriz in Iran. Data regarding the properties of the aggregates and the ash particles are given in Table1.

Table 1: Properties of aggregate and Ash

Aggregate type	Specific gravity	Absorption (%)	Fineness modulus	Unit weight (kg/m3)
Coarse aggregate	2.46	2.56	NA	1684.7
Fine aggregate	2.54	4.91	3.16	1760.4
Incinerator Ash Particles	1.17	17	3.07	1160.2

Coarse aggregate: Natural coarse aggregate of maximum size 25 mm and Unit weight of 1684.7 kg/m^3 was supplied from Charm Shahr (the Tabriz region) in Iran.

Incinerator Ash: Ash particles provided by Tabriz Petrochemical Company in Iran. The Chemical composition of Incinerator Ash is presented in table 2. This type of ash obtain from the burning of solid and liquid wastes, including oil and biological sludge that are remained from refining physical and chemical industrial wastewater in special furnaces. Combustion of west materials creates a solid waste called ash, which can contain any of the elements that were originally present in the waste. Incinerators reduce the solid mass of the original waste by 80–85% and the volume by 95-96 %, depending on composition and degree of recovery of materials such as metals from the ash for recycling. The combustion of these materials reducing the creation of new landfills. A Sample of the Incinerator Ash is shown in Fig. 1.

Table 2: Chemical composition of Incinerator Ash

Compounds	Abbreviation	% Weight
Iron oxide	Fe_2O_3	47.3
Lime	CaO	18.6
Phosphorus pent oxide	P_2O_5	13.5
Alumina	Al_2O_3	2.27
Magnesia	MgO	1.84

Fig.1. Sample of Incinerator Ash.

2.2. Mixture proportioning

The experimental setup and specimen fabrication are summarized in Tables 3 and 4, respectively. To unify the Ash content, a designated percentage for each mix type was converted to a total fine aggregate volume percentage. The equivalent values of Ash content by total fine aggregate volume are given in Table 3. Specimens were remolded 24 hour after casting, and were kept in a curing room at a temperature of 25 ºC, with a relative humidity of 60%, until the time of testing. A normal, non-air-entrained, Portland cement concrete, with a 40 MPa targeted compressive strength, was designed as the control mix according to B.S.1881, part 7. The mix required a 0.48 water–cement ratio. Other constituents are given in Table 4 for P and F specimens. This control mix was used as the basis for preparing new concrete mixes specified by F mixes. In the F mixes, the sand in the control mix was replaced by Ash particles. Several specimens were fabricated from F mixes, wherein Incinerator ash was used with a percentage of 0, 10, 20, 30, up to 80, by total weight of the fine aggregate in concrete.

Table 3: Experimental program

Specimen designation	Incinerator Ash aggregate (%)	Fine mineral Aggregate (%)	Coarse mineral Aggregate (%)	Replication compressive test
p	0	100	100	3
F_{10}	10	90	100	3
F_{20}	20	80	100	3
F_{30}	30	70	100	3
F_{40}	40	60	100	3
F_{50}	50	50	100	3
F_{60}	60	40	100	3
F_{70}	70	30	100	3
F_{80}	80	20	100	3

Table 4: Concrete mixture proportions

Specimen	Cement (kg)	Ash Aggregate	gravel	sand	W/C
p	406	0	1027	747	0.48
F10	406	74.7	1027	672.3	0.48
F20	406	149.4	1027	597.6	0.48
F30	406	224.1	1027	522.9	0.48
F40	406	298.8	1027	448.2	0.48
F50	406	373.5	1027	373.5	0.48
F60	406	448.2	1027	298.8	0.48
F70	406	522.9	1027	224.1	0.48
F80	406	597.6	1027	149.4	0.48

2.3. Specimen and tests of specimens

Cubes of concrete of 150×150×150 mm were molded for compressive strength, and fresh and dry density tests.

2.4. Test of specimens

1. Casting, compaction and curing: Accomplished according to B.S.1881, part 7 and B.S.1881, part 6.
2. Slump test: Fulfilled according to B.S.1881, part 2.
3. Fresh densities: Measured for all cubes after molding and compacting immediately according To B.S.1881, part 5. The fresh density represents the mean of fresh densities for 3 cubes.
4. Compression strength test: Concrete cubes were prepared according to B.S.1881, part 7. The Forney machine was used for the compression test. The cubes were tested immediately after taken out of water while they were still wet. The average of compression strength of 3 cubes was recorded for each testing age (British Standard Institution, 1952).

3. Results and Discussion

1. Slump test: The results of the slump tests indicate that the slump is decreasing with increasing the ash particles ratio. The reductions of slump are 39.29%, 67.72%, 77.54% and 88.42% for F20, F40, F60 and F80, respectively. This reduction can be attributed to the fact that the water absorption of ash particles is more than the natural fine aggregate. So that the replacement of Incinerator Ash in concrete mixtures reduced workability and in order to have normal concrete workability, the mixture needs extra water .in precast applications and large sites based on the following consideration: Workability has a broad range from very low (at slump = 0–25 mm) applied for vibrated concrete in roads or other large sections, to high workability (at slump = 100–180 mm) applied for sections with congested reinforcement (Koehler and Fowler, 2003). Concrete products with incinerator ash are able to use in low slump needs in ordinary constructions.

2. Unit weight: The unit weight of the concrete ranged from 2386 to 2156 kg/m^3, depending on ash content. The results indicate that the Unit weight tends to decrease by different percentage of ash particles replacement in normal concrete. The unit weights of the F_{10}, F_{50}, and F_{80} mixes were reduced 2.3%, 6.43%, and 9.64%, respectively, compared to plain concrete. This trend may be attributed to the density of the waste ash being lower than the sand by 34.1%, which leads to a reduction in the density. Thus, concrete containing incinerator ash could be used wherever

lightweight concrete is required. Due to the high water absorption of ash particles, the ratio of the fresh concrete unit weight to the hardened unit weight in new concrete is greater than that of plain concrete. Therefore, Incinerator Ash concrete is expected to be more porous than plain concrete.

3- Water absorption: The results indicate that the water absorption of concrete containing ash per different percentage of ash replacement has variable behavior. Due to increasing the replacement of ash particles with natural sand in concrete from 10% to 40%, the water absorption increased gradually but in 50 % the water absorption decreased and again from 60% to 80% water absorption of fresh concrete increased. The concrete containing 10 and 50 % ash replaced with natural sand, have the lowest water absorption even lower than the absorption of normal concrete. The highest water absorption is related to the concrete that containing 40 % of ash aggregates as fine aggregates**.**

4. Compressive strength: The results of the compressive strength tests for the Incinerator Ash concrete mixtures are shown in Fig. 4 and loading states of cubic specimens containing incinerator ash with a percentage of 0, 10, 20, 40, 60 and 80, by total weight of the fine aggregate in concrete, as shown in Fig. 5. By increasing the Ash ratio, the results show a tendency for compressive strength values of Incinerator Ash concrete mixtures to decrease below the plain mixtures. The results are in a good agreement with the findings of Marzouk et al (2007) which demonstrated that once the sand volume substituted with aggregates increased, the compressive strength of composites decreased slightly in comparison with the reference mortar. This trend can be attributed to the decrease in adhesive strength between the ash particles and the cement paste. The higher water absorption of ash particles may restrict the water necessary for cement hydration from entering through the structure of the concrete specimens during the curing period. The Hardness of Ash particles is lower than the natural sand particles so it may be attributed to the compressive strength of the concrete containing ash particles being lower than the concrete containing sand as fine aggregate. Its recommended that in order to preparing this kind of concrete, other materials of concrete - except of ash particles- blending to each other and after five minutes ash particles added to the mixture. This process will improve the concrete characteristic and may not restrict the water necessary for cement hydration during the curing period. Except the samples that all fine aggregates replaced by ash particles, all of the compressive strength values are higher than the minimum compressive strength required for structural concrete which is 17.24 MPa.

Juric et al (2006) stated that satisfactory quality of concrete with low strength requirements (compressive strength up to 40 MPa) may be achieved using two waste materials, namely C&D debris and MSW BA, simultaneously.

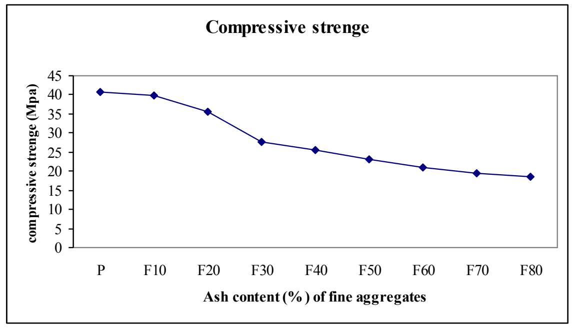

Fig.4. Compressive strength of concrete containing Ash particles.

Fig. 5. Loading of cubic specimens with a percentage of 0, 10, 20, 40, 60 and 80, by total weight of the fine aggregate in concrete.

4. Conclusions

From the results presented in this paper, using concrete Containing Incinerated Industrial Ash, the main conclusions are:

1. The slump values of waste Ash concrete mixtures showed a tendency to decrease below the slump of the reference concrete mixture. Workability of new concrete with fine ash particles is reduced with increasing ash concentration.

2. The unit weights values of waste Ash concrete mixtures with increasing ash particles concentrations present lower unit weights

compared to plain concrete. At 28 days curing age, the lowest density (2156kg/m^3) exceeds the range of the density of structural lightweight concrete.

3. The compressive strength values of all waste ash concrete mixtures tend to decrease below the values for the reference concrete mixtures with increasing the ash particles ratio at all curing ages. This may be attributed to the decrease in the adhesive strength between the surface of the ash particles and cement paste and these particles may restrict the hydration of cement.

4. The water absorption of concrete mixtures that contain Incinerator Ash has variable behavior. The concrete containing 50 % ash replaced with natural sand, have the lowest water absorption even lower than the normal concrete.

5. The experimental results confirm the possibility of casting concrete with a combined use of Incinerator ash as aggregates. The experimental results show that incinerator ashes reused as aggregates replacement can represent an interesting alternative to final landfill disposal. All the ashes analyzed in this work, produced by different incineration facilities, show a good chemical and physical quality for the production of concrete mixtures, whose final mechanical quality is acceptable for different applications.

References

1. Bertolini, L., Carsana, M., Cassago, D., Curzio, A. Q.,and Collepardi, M. (2004). MSWI ashes as mineral additions in concrete. Cement and Concrete Research, 34:1899–1906.
2. British Standard Institution. (1952). Methods of testing concrete. B.S.1881, BSI, London.
3. Chen, H. J., Wang, Sh. Yu., and Tang, Ch. W.(2010).Reuse of incineration fly ashes and reaction ashes for manufacturing lightweight aggregate. Construction and Building Materials, 24:46–55.
4. Federal Highway Administration (FHWA). (1997). User Guidelines for Waste and By-product Materials in Pavement Construction, Washington DC: FHWA-RD; P. 97-148.
5. Ferreira, C., Ribeiro, A.,and Ottosen, L. (2003). Possible applications for municipal solid waste ash. Journal of Hazardous Materials, B96: 201–216.
6. Filipponi, P., Polettini, A., Pomi, R.,and Sirini P.(2003).Physical and mechanical properties of cement-based products containing incineration bottom ash. Waste Management, 23:145–156.
7. Hossam, F. H. (2005).Recycling of municipal solid waste incinerator ash in hot-mix asphalt concrete. Construction and Building Materials, 19: 91–98.
8. Juric, B., Hanzic, L., Ilic, R., and Samec, N. (2006).Utilization of municipal solid waste bottom ash and recycled aggregate in concrete. Waste Management, 26:1436–1442.
9. Koehler, E. P., and Fowler, D.W. (2003). Measuring the workability of high fines concrete for aggregate. International Center for Aggregate Research, University of Texas at Austin, ICAR 105.
10. Mangialardi, T. (2001).Sintering of MSW fly ash for reuses as a concrete aggregate. Journal of Hazardous Materials, B87: 225–239.
11. Marzouk, O.Y., Dheilly, R. M., and Queneudec, M. (2007).Valorization of post-consumer waste plastic in cementitious concrete composites. Waste Management, 27: 310–318.
12. Rafat, S. (2010). Use of municipal solid waste ash in concrete. Resources, Conservation and Recycling, 55: 83-91.
13. Rebeiz, K.S.,and Mielich, K.L. (1995). Construction use of municipal-solid-waste ash. Journal of Energy Engineering - ASCE; 121 (1): 2–13.
14. Walter, C.E. (1976).Practical refuses recycling. Journal of the Environmental Engineering Division , ASCE, 102 (EE1): 139–48.