Utilization of Municipal Solid Waste Ash in Concrete by partial Replacement of Cement

Faaeza Ahmed Abd Ul-Kareem

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Abstract

The problem of solid waste is being emerged increasingly due to the increased quantity of solid waste as a result of population’s increase. From the point of view of environmental and energy concerns, it is preferable to reuse the organic and inorganic components of solid waste in order to minimize the cost. In this investigation, the possibility of using solid waste ash (SWA) as a partial replacement of cement and its effect on the mechanical properties of concrete was studied. Samples of municipal solid wastes were collected were burring and changed to ash. A total of 50 cubes, 15 small cubes, and 30 cylinders, as well as 5 prisms were prepared. Various properties of solid waste ash are added to the cement mixtures with percent's of 5, 10, 15 and 20 percent by weight of solid waste ash. A concrete mix with a percent solid waste ash was used as reference. Pozzolanic activities of all mortars, and setting times of all pastes, and workability of all mixes were investigated. Compressive strength, splitting tensile strength, absorption, and drying shrinkage for reference and solid waste concrete specimens were investigated at various ages. Results demonstrate that the pozzolanic activity was within ASTM requirements for the cases of 5% and 10% ash replacement. For 15 and 20 percent replacement this activity was only slightly less than the ASTM value. The 90-day compressive strength rose, in comparison with control specimens, with 5 percent replacement and was only slightly lower at 10 percent replacement. In splitting tensile strength was at least equal to reference specimens for all replacement ratios. The rise in these values, over the reference specimens, ranged between 0 to 21 percent for the case of 20 and 5 percent replacement, respectively.

Key Words: Solid waste, bottom ash, pozzolanic activities, compressive strength, splitting tensile strength, absorption and drying shrinkage.

استخدام رماد المخلفات الصلبة كجزء بديل عن السمنت في الصبات الخرسانية

فائزة احمد عبد الكريم

الخلاصة

تعتبر مشكلة التخلص من المخلفات المنزلية من المشاكل الحساسة والخطرة وذلك بسبب كمية المخلفات المنزلية الناتجة عن زيادة السكان. من الناحية الاقتصادية وآخذ مشكلة الطاقة بظير الاعتبار من المفضل يتم تدوير أو إعادة استعمال العناصر العضوية وغير العضوية المخلّفة للصلبة المنزلية بصورة اقتصادية. في هذا البحث تم دراسة استخدام رماد المخلفات المنزلية كعوام جزء من السمنت في الخلاطات الخرسانية وتأثيره على الخواص الميكانيكية للخرسانة. اخحت عينات من مخلفات صلبة في 5%,10%,15% و20% نسبة من رماد المخلفات الصلبة وذلك بعمل خلطات خرسانية تحوي على من وزن 5% 15% 10% 20% 50% سمنت. اخترعت الخلاط الخرسانية المنزلية من رماد المخلفات المنزلية هي الخلاط المرجعي لغرف المغارة. اختبرت النتائج البيئية اللوزولانية لكل نوع المونة المنزلية على نسبة المخلّفة لرماد الخلاطات والخالية منه وكذلك زمن الصلب للسمنت يوجد النسبة المخلّفة لرماد اجبرت خصوص البطن، مقاومة الانضغاط، شديد الاتصال بالاستخدام، والانكماش للخلاط الخرسانية والخلاطات المنزلية على النسبة المخلّفة من رماد المقلّفات الصلبة وتأثر مناسبة. البناء من النتائج البيئية الولوزولانية للخلطات الخلع دينين على نسبة 5% 10% 15% 20% 50% رماد المخلّفات وهي ضمن متطلبات المواصفة الأمريكية ASTM للخلطات اللاحويين على 5% 15% 20% 50% 100%.

1 Lecture, Building and Construction Engineering Department /University of Technology/Iraq/Baghdad
1. Introduction
Solid waste is the unwanted or useless solid materials generated from combined residential industrial and commercial activities in a given area. It may be categorized according to its origin (domestic, industrial, commercial, construction or institutional) according to its contents organic material, glass, metal, plastic paper, etc); or according to hazard potential (toxic, non-toxin, flammable, radioactive and infectious, etc.). [1]

Portland cement can be known as a power exhaustive material, then considerable effort is being made to find substitutes for partially replacing cement in concrete. For over 30 years the world had become increasingly involved in research aiming at power in the cement and concrete manufacturing. This was partly accomplished by encouraging the use of less energy intensive cementations materials for example, rice husk ash, fly ash, slags, condensed silica fume and pozzolans in concrete. [2]

In this study solid, local SAW is used as a partial replacement of cement in concrete. Results of this research will provide important information about the pozzolanic activity of Iraqi SAW, the setting time, the compressive strength, the splitting strength, absorption, and drying shrinkage of concrete, the splitting tensile strength, absorption, and drying shrinkage of concrete, which contain Iraqi solid ash as a partial replacement of cement.

2–Experimental Program
Samples of Municipal Solid Waste used throughout this work. The samples were collected from different points of beds. The first step in the preparation of solid waste to be used as a replacement of cement in concrete was its combustion with air. Dewatered solid samples were fired in an electric furnace with controlled temperature in order to establish the optimal burning temperature and time. The resulting ash was pulverized and only components that passed through the 150 µm sieve. The experimental program was planned to investigate the effect of using solid as a partial substitution of cement in concrete on the mechanical properties of concrete. The test variables include slump, compressive strength, splitting tensile strength, drying shrinkage, and absorption.

2–1 Materials
2–1–1 Cement
The physical analysis and chemical tests results of the cement use are given in table (1) and (2), respectively. They conform to the Iraqi specification No. 5/1984. [15]
Table 1. Chemical analysis of cement

| Compound Composition | Abbreviation | Percentage by Weight | Limits of Iraqi Spec. No. 5/1984 |
|----------------------|--------------|----------------------|----------------------------------|
| Lime                 | CaO          | 61.8                 |                                  |
| Silica               | SiO₂         | 22.2                 |                                  |
| Alumina              | Al₂O₃        | 4.4                  |                                  |
| Iron oxide           | Fe₂O₃        | 2.7                  | ≤ 2.8%                          |
| Sulfate              | SO₃          | 2.7                  |                                  |
| Magnesia             | MgO          | 2.5                  | ≤ 5%                            |
| Loss on Ignition     | L.O.I        | 1.9                  | ≤ 4%                            |
| Lime saturation factor | L.S.F.     | 0.87                 | 0.66-1.02                       |
| Insoluble residue    | I.R          | 1.5                  | ≤ 1.5                           |

Main compounds (Bogus equation) percentage by weight of cement

| Main compounds (Bogus equation) | Percentage by weight of cement |
|---------------------------------|--------------------------------|
| Tricalcium silicate (C₃S)       | 48.65                          |
| Dicalcium silicate (C₂S)        | 27.3                           |
| Tricalcium aluminate (C₃A)      | 7                              |
| Tetracalcium alumina ferrite (C₃AF) | 13.4                          |

Table 2. Physical properties of cement

| Physical properties | Test result | Limits of Iraqi Spec. No.5/1984 |
|---------------------|-------------|----------------------------------|
| Specific surface area Blaine Method, m²/kg | 379          | ≥ 230 m²/kg                      |
| Setting time, Vicats method : | | 3:17                            |
| Initial setting hrs :min | | ≥ 1 hour                        |
| Final setting hrs:min | |                                |
| Soundness | | .2%                             |
| Compressive strength of Mortar, N/mm | | .8%                            |
| 3-day | | 15.8                           |
| 7-day | | 27.5                            |
| | | ≥ 15N/mm²                       |
| | | ≥ 23N/mm²                       |

2-1-3 Fine Aggregate

The sieve analysis of the sand used is given in Table (3). It conforms to the limits of Iraqi specification No.45/1984[16], Zone(3). The specific gravity, absorption, sulphate content and material finer than sieve No.(75) of fine aggregate were (2.62,1.19%, 0.2% and 0.8%) respectively.

Table 3. Gradation of fine aggregate

| Sieve size (mm) | Accumulated Percentage passing % | Limit of Iraqi specification No.45/1984 |
|-----------------|----------------------------------|----------------------------------------|
| 4.47            | 100                              | 90-100                                 |
| 2.36            | 93                               | 85-100                                 |
| 1.18            | 90                               | 75-100                                 |
| 0.6             | 75                               | 60-79                                  |
| 0.3             | 37                               | 12-40                                  |
| 7.5             | 7                                | 0-10                                   |

2-1-4 Fly Ash

Fly ash is the result of the burning of pulverized coal in thermal power plant life. It is removed by perfunctory collector or electrostatic precipitators as a fine particulate residue from the incineration gases
before they are discharge to the environment [3]. A combustion and properties of fly ash vary somewhat from one fly ash to another, depending on the specific coal being burned and on the details of the power station equipment and operating conditions [4][5].

2–1–5 Properties of Solid Waste Ash
The generated solid waste ash from incinerator involves wide range of particles size; only the fraction 0-4 mm was used in the present work. The ash was dried before experiments. The content of major components (in form of oxides) is presented in Table 4.

| Content | SiO$_2$ | Al$_2$O$_3$ | Fe$_2$O$_3$ | CaO | MgO | S$_2$O$_3$ | ZnO | Na$_2$O | K$_2$O | TiO$_2$ | Cl |
|---------|---------|-------------|-------------|------|-----|-----------|-----|--------|-------|-------|----|
| Percentage | 33.5 | 15.8 | 8.4 | 19.4 | 2 | 9.3 | 0.8 | 3.6 | 1.9 | 1.5 | 1.1 |

2–1–7 Pozzolanic Activity Index of Solid Waste Ash
The W/C or W/C+SOA ratio and pozzolanic activity index for various mixes are presented in table (5). Fig (1) shows the pozzolanic activity index in percentages.

| Index | SWA% by wt of cement | W/C or W/C+SWA | Flow | P.A.I% |
|-------|----------------------|-----------------|------|-------|
| M     | 0                    | 0.5             | 113  | 78.1  |
| M-5% SWA | 5              | 0.6             | 115  | 75   |
| M-10% SWA | 10             | 0.62            | 112  | 73   |
| M-15% SWA | 15             | 0.65            | 113  | 70   |
| M-20% SWA | 20             | 0.68            | 113  | 78.1 |

2–1–8 Concrete Mix Design
The concrete mix up was intended in accordance with the method of the American Concrete Institute, given in ACI Standard 211.1-77. The compressive strength, maximum size of aggregate, workability, and fineness modulus of sand were considered the principal factors governing the mix design. The reference concrete mix designed to have a 28-day compressive strength of about (28)MPa and slump (30-80)mm. The SWA-Concrete mixes were designed with the same weight proportions except that a(5,10,15 and 20)% of the cement weight was replaced by SWA. The (W/C+SWA) was the same as (W/C).[6,7]

2–1–9 Casting, Compaction and Curing
The molds were tightly coated with mineral oil before use, according to ASTM C192-88 [9]. Concrete casting was carried out in two layers each layer of 50 mm. Each layer was compacted by using a vibrating table for (15-30) seconds until no air bubbles emerged from the surface of the concrete, and the concrete was leveled off smoothly to the top of the molds. Then the specimens were kept covered with polyethylene sheets in the laboratory for about (24+2) hour's. After that the specimens were remolded carefully, marked and immersed in water until the age of test. The ages of tests were 28, 60 and 90 day.

3– Testing
3–1 Determination of the workability
Workability of all types of concrete was measured by slump test according to the procedure described in ASTM C143-89. [8]
3–2 Hardened Concrete Tests
For compressive strength tests 100mm side concrete cubes were prepared according to B.S.1881. part 3, 1983 [10]. The compressive strength was determined using a (2000KN) capacity ELE digital testing machine of three cubes was recorded for each testing at age of 28, 60 and 90 day.

3–3 Splitting Tensile Strength
Concrete cylinders were prepared in (100*200) mm (dim. hig). The splitting tensile strength test was carried out according to ASTM C496-86 [11].

The load was applied by using (2000kN) capacity ELE digital testing machine, continuously at a stress rate of 6 MPa per minute. Three cylinders was recorded for each testing time 28, 60 and 90 day of the average of splitting tensile strength.

3–4 Absorption Test
The test was performed on 100mm cube in a accordance with B.S.1881:part 122:1989[12]. For each mix 2 cubes were taken from the curing basins and over dried to 105C 72hrs. Then they were wrapped securely with a polyethylene sheet and left in the laboratory to cool for 24 hrs.

After that they were weighted and then immersed in the water. After the immersion period of 30 minute, the cubes were removed and their surface were dried with a cloth and weighted again.

3–5 Drying Shrinkage Test
Prisms with dimension of (100*100*400) mm (weight * depth * length) were prepared and cast according to ASTM C192-88[6]. Then they were demoded after 24 hour, and a stainless steel demec point was fixed on two parallel faces of specimens with a distance of 150mm between them in each face, after they were placed in a tank filled with tap water for 7 days. After that they were stored in a dry place inside the laboratory at a temperature of about 28C and relative humidity of 26. The change length of specimen was measured by means of a dial gage of strain satisfy the requirement of ASTM C490-89 [14]. The measuring device gage is 0.002 the shrinkage was measured at the ages of 7, 14 and 28 day.[13]

4– Results and Discussion
4–1 Setting Time
Initial and final setting times for reference and replaced cement paste samples are given in Table(6) and Figure 1. It is observed that the addition of solid waste ash due to replace of cement amount which effect on hydration process and consequently on setting time delays the setting times for the cement.

| Percentage of Solid Ash | Setting Time (hrs :min) |
|------------------------|------------------------|
|                        | Initial                | Final                  |
| 0                      | 3:15                   | 4:45                   |
| 5                      | 3:30                   | 5:50                   |
| 10                     | 3:40                   | 5:25                   |
| 15                     | 3:40                   | 5:30                   |
| 20                     | 3:50                   | 5:30                   |
The slump test results for all types of mixes are presented in table (7) and figure 2. Generally, workability appears to improve with higher percentages of sludge ash in the concrete. This result shows agreement to that which was found by previous researches. Thus, it seems at this stage, SWA concrete does not cause a workability problem because the SWA is a soft material and not effective on workability.

**Table 7. Slump for Various Mixes**

| percentage of solid ash | W/C or W/C | Slump(mm) |
|-------------------------|------------|-----------|
| 0                       | 0.55       | 60        |
| 5                       | 0.55       | 55        |
| 10                      | 0.55       | 53        |
| 15                      | 0.55       | 50        |
4–3 Compressive Strength

The compressive strength values at 28, 60 and 90-day ages for reference and various mixes with partial replacement of cement by solid waste ash are shown in table (8). The results indicate that sluge ash concrete with 5% replacement showed an increase in compressive strength at all ages of tests relative to its reference concrete, Figure 3. The compressive strength as the percentage of solid ash increased because of increasing the density of concrete matrix.

Table 8. Compressive Strength of Reference and Various Mixes with SWA

| Symbol            | Cement Content (kg/m³) | Solid Ash Content (kg/m³) | W/C or W/C+SWA | Compressive Strength (Mpa) |
|-------------------|------------------------|---------------------------|----------------|---------------------------|
|                   |                        |                           |                | 28 day | 60 day | 90 day |
| Reference concrete| 321                    | 0                         | 0.55           | 28     | 30     | 33     |
| 5% SWA-concrete   | 317                    | 15.6                      | 0.55           | 27     | 32     | 34     |
| 10% SWA-concrete  | 310                    | 31.6                      | 0.55           | 25     | 29     | 30     |
| 15% SWA-concrete  | 266                    | 52.1                      | 0.55           | 24     | 27     | 29     |
| 20% SWA-concrete  | 270                    | 64.3                      | 0.55           | 25     | 26     | 28     |

Figure 3. Compressive Strength of Reference and Various Mixes with SWA

4–5 Splitting Tensile Strength

The splitting tensile strength development at 28, 60 and 90 days for all types all types of concrete is presented in table (9) and figure 4. Results indicate that the solid ash concrete with all percentage of replacement showed considerable increase in splitting tensile strength at all ages of tests relative to its reference concrete because of decreases of in tensile strength of concrete.
Table 9. Splitting Tensile Strength of Reference and Various Mixes with SWA

| Symbol            | Cementation Material Content | W/C or W/C+SWA | Splitting Tensile Strength Mpa |
|-------------------|-----------------------------|----------------|-------------------------------|
|                   | Cement content (kg/m³) | Solid ash content (kg/m³) | 28 (day) | 60 (day) | 90 (day) |
| Reference concrete| 335                        | 0               | 0.55                         | 1.66    | 2.14    | 2.5     |
| 5%SWA-concrete    | 317.3                      | 17.7            | 0.55                         | 2.15    | 2.17    | 2.82    |
| 10%SWA-concrete   | 300.9                      | 33.5            | 0.55                         | 1.8     | 2.14    | 2.7     |
| 15%SWA-concrete   | 283.9                      | 50.2            | 0.55                         | 1.5     | 2.15    | 2.7     |
| 20%SWA-concrete   | 267.5                      | 66.5            | 0.55                         | 1.6     | 2.4     | 2.6     |

Figure 4. Splitting Tensile Strength of Reference and Various Mixes with SWA

4–6 Absorption
The results of the absorption test for various type of concrete specimens are given away in table (10) and Figure 5. As shown in table (10), water absorption for samples do not significant vary with the percentages of pulverized sludge ash used in concrete. Results show an agreement to those which were found by previous studies.

Table 10. Absorption of and Various Mixes of Concrete

| Symbol          | Cementation Material Content | W/C or W/C+SOA | Absorption % |
|-----------------|-----------------------------|----------------|--------------|
| Reference       | 321                         | 0              | 2.1          |
| 5%SOA-concrete  | 322                         | 15.6           | 2.3          |
| 10%SWA-concrete | 310                         | 31.6           | 2.6          |
| 15%SWA-concrete | 266                         | 52.1           | 2.5          |
| 20%SWA-concrete | 270                         | 64.3           | 2.6          |
The results of the drying shrinkage test for all types of concrete specimens are shown in Table 11 and Figure 6.

**Table 11. Results of Drying Shrinkage Test**

| Symbol               | Cementation Material Content | W/C or W/C+SWA | Drying Shrinkage Strain ($10^{-6}$) |
|----------------------|-----------------------------|----------------|-------------------------------------|
|                      | Cement content (kg/m$^3$)   | Solid ash content (kg/m$^3$) | 28 day | 60 day | 90 day |
| Reference concrete   | 321                         | 0              | 0.55                  | 750     | 820     | 890     |
| 5% SWA-concrete      | 322                         | 15.6           | 0.55                  | 720     | 755     | 821     |
| 10% SWA-concrete     | 310                         | 31.6           | 0.55                  | 750     | 850     | 828     |
| 15% SWA-concrete     | 266                         | 52.1           | 0.55                  | 760     | 780     | 830     |
| 20% SWA-concrete     | 270                         | 64.3           | 0.55                  | 740     | 750     | 866     |

**Figure 5. Absorption of and Various Mixes of Concrete**

**4–7 Drying Shrinkage**

**Figure 6. Drying Shrinkage strain**
5- Conclusions

1- Incinerating solid wastes is an efficient method compared with land filling to reduce the non-recyclable waste amount; the waste reduced by incineration is less than 30% of original mass and the volume decrease is about 10%.

2- The pozzolanic activity of the mortars decreases as the percentage of solid ash used increases. However, with 5% and 10% replacement of cement by solid ash.

3- The is a slight decrease in the initial and final setting times with an increase in the amount of replaced by solid waste ash.

4- Solid waste ash concretes showed significant reduction in drying shrinkage at all age compared to reference concrete.

5- The concrete which has fly ash is an effective technique for the frost resistance.

6- The high percent fly ash without any accompanied loss of concrete properties possible only when the fly ash is treated by using vitrification method. Where in such case there is arise additional costs suppressing the MSWI ashes utilization attractiveness for building industry.

7- Solid waste ash concretes exhibit a slight improvement in workability relative to their reference concrete.

Reference

1. Kiely ,G.(1997), “Environmental Engineering “McGraw-Hill International
2. Carette, G.G and Malhotra ,V.M.,1983,”Mechanical Properties, Durability and Drying Shrinkage of Portland Cement Concrete Incorporating Silica Fume”, Cement Concrete and Aggregates, CCAGDP,Vol.5,No.1,Summer 1983,pp.3-13.
3. Berry ,E.E. and Malhotra ,V.M., “Fly Ash for use in concrete –Acritical Review”1980,Vol77,No.2, pp.59.
4. Olek J. and Diamond , S.,”Propertioning of Constant Paste Composition Fly Ash Concrete Mixes”, ACI Materials Journal,Vol. 86, No.2,March-April 1989,pp159-166.
5. Cook, E.J., 1983 "Fly Ash in Concrete-Technical Considerations",Concrete Internation : Design and Construction ,Vol.5,No.9.
6. J. Pera, L. Coutaz, J. Ambroise and M. Chababbet, “Use of Incinerator Bottom Ash in Concrete”, Cement and Concrete Research, vol. 27, 1997, pp. 1–5.
7. M. Ferraris, M. Salvo, A. Ventrella, L. Buzzi, L. and M. Veglia, , 2009 “Use of Vitrified MSWI Bottom Ashes for Concrete Production”, Waste Management, vol. 29, pp. 1041–1047.
8. ASTM C143-89 ,"Standrad Test Method for Slump of Hydraulic Cement Concrete “Annual Book of ASTM Standards American Society for testing and Materials,Philadelphia. Vol.4.
9. ASTM C143-89 ,"Standrad Test Method for Slump of Hydraulic Cement Concrete “Annual Book of ASTM Standards American Society for testing and Materials,Philadelphia. Vol.4.
10. ASTM C192-88 “Standrad Practice for Making and Curing Test Specimens in the Laboratory”,Annual Book of ASTM Standarads American Society for testing and Materials,Philadelphia.vol.04.02,1989,pp.112-118.
11. British Standard Institution,1970,"Method of Testing for strength,"B.S.1881,Part3,Lond.
12. U. Müller and K. Rühner, “The microstructure of concrete made with municipal waste incinerator bottom ash as an aggregate component”, Cement and Concrete Research, vol. 36, 2006, pp. 1434-1443.
13. British Standard Institution , 1970,"Method for Making and Curing Concrete Test Specimens",B.S.1881,part3,Lond.
14. ASTM C490-89,"Standrad Specification for Apparatus for Use Measurement of Hardened Cement Paste,Annual Book of ASTM Standards American Society for testing and Materials,Philadelphia.vol.04.1989,pp.244-247.
15. Martin kepert ,Zbysek pavlik, Robert Cerny,2015 , “Properties of Municipal Solid Waste Incinerator Ash in Concrete”IPCSI ,Vol 28
16. M.Ferraris,M.Salvo,A.Venterlla,2014,"Study on MSW Incineration Ash in Concrete with partial replacement of cement"
17. Meenaksi Dixit, Atishaya jain, 2016, “Effect on compressive strength of concrete with partial replacement of cement by municipal solid waste incinerator ash “, International journal of Civil Engineering , (SSRG-IJCE) – Vol.3.
18. Keport,M.,Pavlik,Z.,2012,“Properties of Concrete with Municipal Solid Waste Incinerator bottom Ash”, IACSIT,Combotar Conferences,Vol28
19. المواصفات القياسية العراقية رقم (45)سنة 1984 "ركام المصادر الطبيعية المستعملة في الخرسانة والبناء".
20. المواصفات القياسية العراقية رقم (45)سنة 1984 "ركام المصادر الطبيعية المستعملة في الخرسانة والبناء".