

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

Faaeza Ahmed Abd Ul-Kareem<sup>1</sup>

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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 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

فايزة احمد عبد الكريم

### الخلاصة

تعتبر مشكلة التخلص من المخلفات المنزلية من المشاكل الحساسة والخطرة وذلك بسبب كمية المخلفات المنزلية الناتجة من زيادة السكان. من الناحية البيئية ويأخذ مشكلة الطاقة بنظر الاعتبار من المفضل يتم تدوير او اعادة استعمال العناصر العضوية وغير العضوية المخلفات الصلبة المنزلية بصورة اقتصادية. في هذا البحث تم دراسة استخدام رماد المخلفات المنزلة كمعوض جزئي عن السمنت في الخلطات الخرسانية وتأثيره على الخواص الميكانيكية للخرسانة. اخذت عينات من مخلفات الصلبة وتم حرقها وتحويلها الى رماد تم تهيئة 50 مكعب و 15 مكعب و 30 اسطوانة بالإضافة الى خمسة مواشير من الخرسانة. تم دراسة تأثير نسب مختلفة من رماد المخلفات الصلبة وذلك بعمل خلطات خرسانية تحوي على من وزن 5,10,15,20% سمنت. اعتبرت الخلطة الخرسانية الحالية من رماد المخلفات المنزلية هي الخلطة المرجعية لغرض المقارنة. اختبرت الفعالية البوزولانية لكافة انواع المونة الحاوية على نسب المختلفة لرماد المخلفات والحالية منه وكذلك زمن التصلب للسمنت بوجود النسب المختلفة لرماد. اجريت فحوص الهطول، مقاومة الانضغاط، شد الانفلاق، الامتصاص والانكماش للخلطة المرجعية والخلطات الحاوية على النسب المختلفة من رماد المخلفات الصلبة وبأعمار مناسبة. بيت النتائج بان الفعالية البوزولانية للخلطتين الحاويتين على 10,5% مادة رماد المخلفات هي ضمن متطلبات المواصفة الاميركية ASTM. للخلطتين الحاويتين على 20 و 15%

<sup>1</sup> Lecture, Building and Construction Engineering Department /University of Technology/Iraq/Baghdad

مادة رماد المخلفات كانت الفعالية البوزلانية اقل بقليل من متطلبات المواصفة الاميركية ASTM. ارتفعت مقاومة الانضغاط بعمر ٩٠ يوم عند استعمال ٥% من وزن السمنت مادة الرماد المخلفات وانخفضت بنسبة ضئيلة جدا عند استعمال ١٠% بينما مقاومة شد الانفلاق في جميع الحالات كانت اما مساوية او أكثر من الخلطة المرجعية لهذه المقاومة بزيادة تتراوح بين ٠-٢١% لاستعمال نسبة ٢٠% و ٥% من رماد المخلفات.

الكلمات المفتاحية : مخلفات صلبة ، رماد داخلي، الفعالية البوزلانية ، فحص الهطول ،مقاومة الانضغاط ، شد الانفلاق ،الامتصاص ،الانكماش

## 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  $\mu\text{m}$  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	SiO <sub>2</sub>	22.2	
Alumina	Al <sub>2</sub> O <sub>3</sub>	4.4	
Iron oxide	Fe <sub>2</sub> O <sub>2</sub>	2.76	
Sulfate	SO <sub>3</sub>	2.7	≤2.8%
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
<b>Main compounds (Bogus equation) percentage by weight of cement</b>			
Tricalcium silicate (C <sub>3</sub> S)			48.65
Dicalcium silicate (C <sub>2</sub> S)			27.3
Tricalcium aluminate (C <sub>3</sub> A)			7
Tetracalcium alumina ferrite (C <sub>3</sub> AF)			13.4

**Table 2. Physical properties of cement**

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

## 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 perfunctorary 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.

**Table 4. The weight percent of major oxides in fly ash**

Content	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	CaO	MgO	So <sub>3</sub>	ZnO	Na <sub>2</sub> O	K <sub>2</sub> O	Tio <sub>2</sub>	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.

**Table 5. Properties of Solid Waste Ash**

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(5,10,15and 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 28,60and 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 2cubes 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 demolded 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 7days. 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 accuracy of 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.

**Table 6. The initial and final setting times of solid waste ash**

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

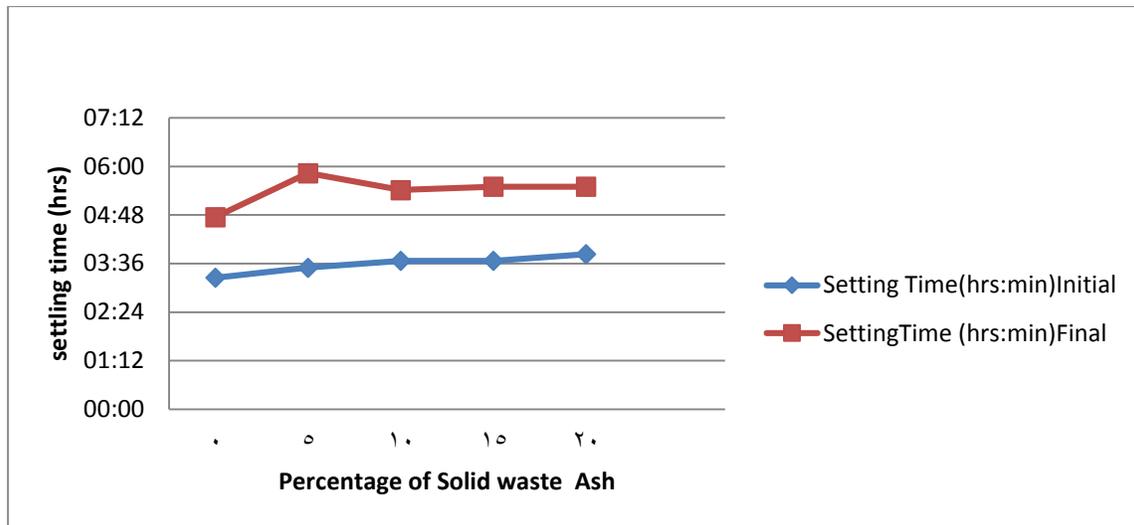


Figure 1. The setting times for the cement

## 4-2 Workability

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 on 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 soft material and not effective on workability.

Table 7. Slump for Various Mixes

percentage of solid ash	W/C or W/C  +SWA	Slump(mm)
0	0.55	60
5	0.55	55
10	0.55	53
15	0.55	50

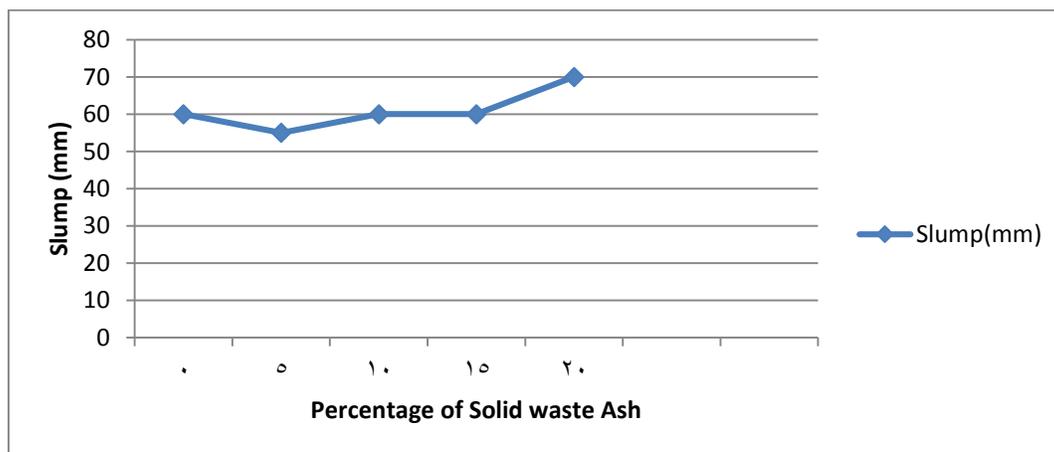


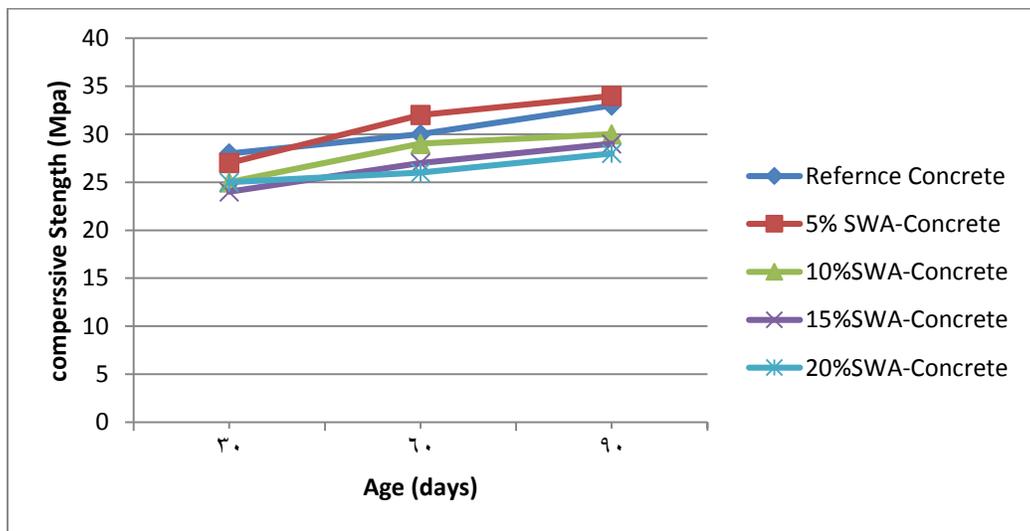
Figure 2. Slump for Various Mixes

### 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	Cementation Material Content			W/C or W/C+SWA	Compressive Strength (Mpa)		
	Cement content (kg/m <sup>3</sup> )	Solid content (kg/m <sup>3</sup> )	ash content (kg/m <sup>3</sup> )		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



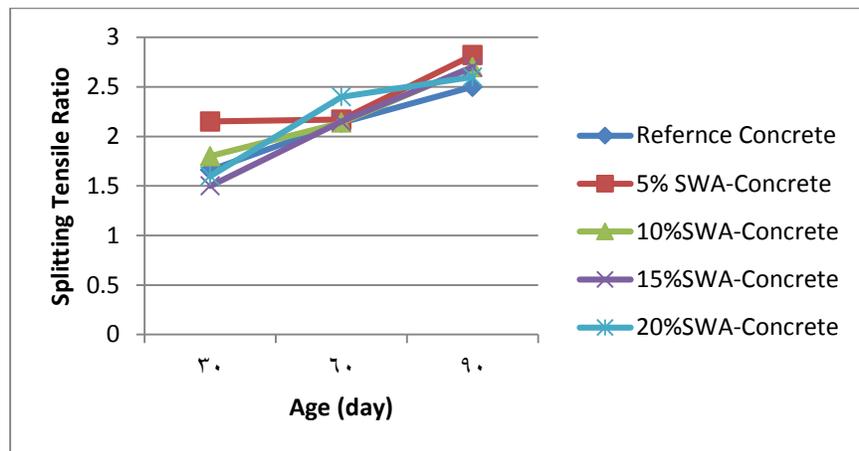
**Figure 3. Compressive Strength of Reference and Various Mixes with SWA**

### 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/m <sup>3</sup> )	Solid ash content (kg/m <sup>3</sup> )		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 %
	Cement content (kg/m <sup>3</sup> )	Solid ash content (kg/m <sup>3</sup> )		
Reference concrete	321	0	0.55	2.1
5%SOA-concrete	322	15.6	0.55	2.3
10%SWA-concrete	310	31.6	0.55	2.6
15%SWA-concrete	266	52.1	0.55	2.5
20%SWA-concrete	270	64.3	0.55	2.6

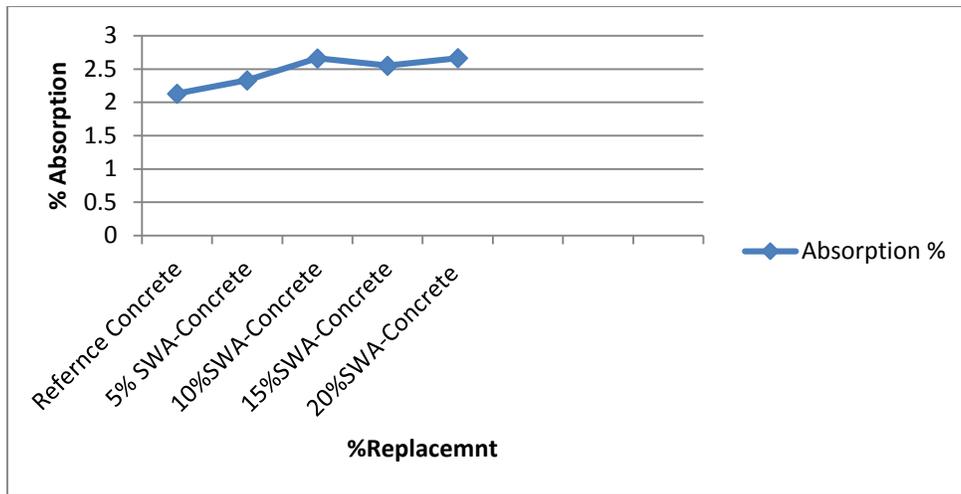


Figure 5. Absorption of and Various Mixes of Concrete

### 4-7 Drying Shrinkage

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 <sup>-6</sup> )		
	Cement content (kg/m <sup>3</sup> )	Solid ash content (kg/m <sup>3</sup> )		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

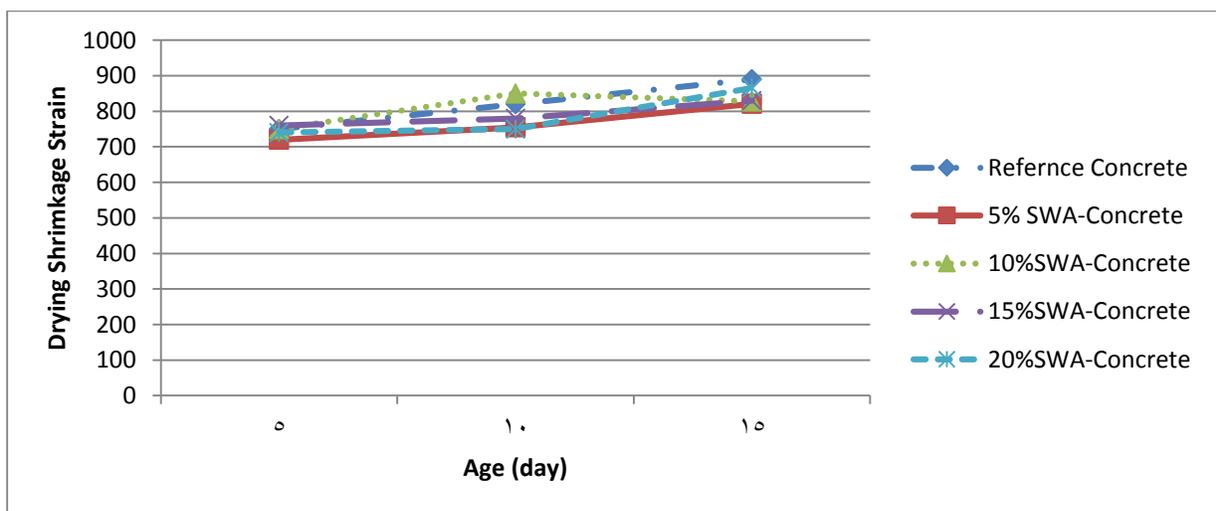


Figure 6. Drying Shrinkage strain

## 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 aslight decrease in the initial and final setting times with an increase in the amount of replaced by solid west 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.

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