Gasification Ash Effect on the Strength and Durability of Reactive Powder Concrete

Isam Mohamad Ali
Karbala Technical Institute, Al-Furat Al-Awsat Technical University, Karbala, Iraq.

Received Date: 5 / 2 / 2018
Accepted Date: 5 / 7 / 2018

الخلاصة

أصبحت مقاومة الخرسانة للتضرر نتيجة التعرض للانجماد والذوبان ومهاجمة الأحماض من الأمور الهامة عند تصميم الخلطة وخلال وضع وإنضاج الخرسانة. كان الهدف الرئيسي لهذه الدراسة التحري عن إمكانية استخدام مخلفات الرماد الغازي من محطة المسيب الغازية كمادة مضافة بديلة عن السمنت لإنتاج خرسانة المساحيق الفعالة. أجريت فحوصات المقاومة والديمومة من أجل الوصول الى فهم واضح للخواص الميكانيكية لخرسانة المساحيق الفعالة والمعرضة لظروف قاسية بأعمار (28 و56) يوماً على التوالي.

أظهرت نتائج الفحوصات ان استخدام الرماد الغازي كمادة سمنتيه بديله له تأثير إيجابي على مقاومة الانضغاط والانشطار لخرسانة المساحيق الفعالة لغاية نسبة (10٪) من الاستبدال. بعد هذه النسبة لم يطرأ اي تحسن اضافي مؤثر لخواص ومقاومة الخرسانة الناتجة. كما ان تعرض خرسانة المساحيق الفعالة لدورات او تراكيز عالية من الانجماد-الذوبان ومهاجمة الاحماض يكون مصحوبا بضرر اعلى مما في حالة التراكيز والدورات الاوطأ..

الكلمات المفتاحية

مخلفات الرماد الغازي، خرسانة المساحيق الفعالة، فحوصات المقاومة والديمومة.

Vol. 10, No. 19 and 20 P. (33-44), Sept., 2019

Abstract

The resistance of concrete to damage due to freezing-thawing and acid attack has become an increasingly important factor to be considered in both mix concrete design and its placing and curing techniques. In this study, the primary goal was to investigate whether a gasification ash GA from Al-Mussaib electrical power station can be used as a supplementary cementitious material in reactive powder concrete RPC. Strength and durability tests were conducted in order to get a good understanding of the mechanical features of concrete exposed to severe conditions at (28) and (56) days respectively.

The results of the experiments show that the use of gasification ash as a supplementary cementitious material has a positive effect on both compressive and splitting strength development of reactive powder concrete up to (10%) of replacement. Above (10%) gasification ash has no further increase in the strength of concrete. The exposure to higher cycles of freezing-thawing and larger concentrations of acid attack have higher detrimental effect than those of lower concentrations.

Keywords

Gasification ash, reactive powder concrete, strength, durability.

1. Introduction

In the last ten years, reactive powder concrete has been widely used in heavy structures as strength and durability are considered the most important factors for designers. Therefore, controlling the ingredients and surrounding environment of concrete is important to its serviceability. Moreover, it is well known that using waste materials in the manufacturing of cement based materials and concrete is an opportunity to reduce its environmental impact [1-2]. This was due to the growing knowledge of the engineering of the economic and ecological benefits that the use of waste materials have in both: cement and concrete composites [3].

In high performance concrete, a part of Portland cement is replaced by pozzolanic admixtures such as metakaolin, fly ash, etc. [4]. After that, the strength and durability of cement based composites were improved due to reducing the number and size of micro pores [5]. Further, the components of fly ash vary considerably depending upon the source of the coal being burned. Silicon dioxide (SiO_2) (both amorphous and crystalline), aluminum oxide (Al_2O_3) and calcium oxide (CaO), the main mineral compounds in coal-bearing rock [6].

Kumar et al [7], has investigated the use ash from burned wasted wood as partial replacement of cement. They mentioned that, the pozzolanic activity index was (75.9%)and it is noticed that (10 %) replacement of cement with sawdust ash shows the desired workability and strength. Abdulabbas [8], examined sustainable industrial waste materials (cement kiln dust) as partial replacement of cement. It was found that the replacement of up to (20%) (CKD) by weight of cement has a negligible effect on strength of concrete. Karthick and Nirmalkumar [9], studied the properties of controlled low strength material made using industrial waste incineration bottom ash and quarry dust. These wastes must be properly managed and disposed without causing any harmful environmental effects. Solanki Y. and Pitroda [10], studied the use of paper mill sludge ash (PA) as supplementary cementitious material. On the basis of data collected, they concluded that PA showed a positive effect on the strength of mortars if used to replace up to (10 %) of Portland cement.

It has been known that cycles of freezing and thawing had detrimental effects on the structure and durability of concrete [11]. In addition, the effects of damage due to freeze-thaw action include cracking, loss of stiffness, increased permeability and eventually scaling and spalling. The most widely accepted hypothesis for the damage caused by freezing and thawing on concrete is that proposed by Jang et al [12]. They found that water expand (9%) when it froze at (6) C. Thus, as water froze in a pores that (91%) fill of water, the resultant expansion due to ice formation forces unfrozen water to flow into the gel structure surrounding the capillaries. When the hydraulic pressure results in stresses exceeding the strength of the paste, cracks occur.

Hydrated cement paste is alkaline; therefore, exposure to acidic waters is detrimental to its mechanical properties and durability. Beulah and Prahallada [13] mentioned "concrete is susceptible to attack by sulphuric acid produced from either sewage or Sulphur dioxide present in the atmosphere of industrial cities". They concluded that, the production of a very dense and impervious concrete is the only way to inhibit the deterioration of concrete by chloride ions. Loss in mass and strength in RPC specimens kept in acidic environment were studied by acid test and visual observation on surface deterioration is also reported. It is noted that sulphuric acid reacts with calcium present in cement and gives paste of gypsum which reduces the concrete strength. It was observed that strength loss is high after immersion in acid solution (5%) of volume of water.

2. Objectives

This paper will address some of parameters in an attempt to further the understanding of acid attack and freeze-thaw phenomena in reactive powder concrete containing gasification ash as a byproduct. So, there were two major goals of this research study. The first goal was to obtain information relating to the effect of using cheap, and local byproduct (gasification ash from Al-Mussaib electrical gas station in Babylon governorate) as a supplementary cementitious material on the strength of reactive powder concrete. In particular, the effect of the added percentage of gasification ash and the age of concrete were of interest. The second goal was to provide information for use in establishing the mechanisms by which the gasification ash improves the resistance of RP concrete to freezing-thawing cycles and acid attack.

3. Materials

The materials used in this research consisted of Type I Portland cement, natural Al-Ekhaider fine aggregate, tap water, a highly efficient high-range water reducer admixture commercially known as (Sika ViscoCrete 5930), gasification ash from ALmsaeb electrical power station (the ash precipitated mechanically before the flue gases reach the chimneys from the exhausted gases of coal-fired power station) and micro Steel fibers. The chemical composition of cement and gasification ash, presented in (Table1), confirmed that cement is complying to Iraqi Specification (No. 5/1984) and the gasification ash conforms to the requirements of (ASTM C-618) class C specification with strength activity index of (105%) at (28) days following the (ASTM C-311/05) specification. In order to get a good understanding of the mechanical features of reactive powder concrete made of gasification ash, it is recommended to sieve the ash in (No. 200) (75) µm sieve.

The fine aggregate used was a quartz based sand that is complying with (B.S. 882/1992), zone F. It was tested to determine the grading and other physical and chemical properties. Results indicated that the fine aggregate grading were within the requirements of the (B.S. 882/1992). For reactive powder concrete, very fine sand with maximum size (600) µm is used. This sand is separated by sieving; its grading satisfies the fine grading in accordance with the (B.S. 882/1992). The sieve analysis of the original (column 2) and the separated fine sand (column 4) is shown in Table (2).

Table (1): chemical composition of cementitious materials*.

Constituent	Cement (%)	Limits of I.Q.S No. 5/1984	Gasification Ash (%)	Limits of ASTM C-618/05
CaO	61.35	---	21.62	
SiO_2	23.59	21 ≤	42.18	% 50 ≤
Al_2O_3	5.13	6 ≥	6.81	
Fe_2O_3	2.27	6 ≥	1.52	
MgO	2.38	% 5 ≥	0.42	
SO_3	2.9	% 2.5 >	0.89	5 ≥
NaOH+KOH	0.46		/	
Loss on Ignition	2.3	% 4 ≥	1.7	% 6 ≥
Insoluble residue	0.87	% 1.5 ≥	/	
Lime Saturated factor	0.96	1.02 – 0.66	/	
Fineness	285 m^2/kg	230 ≤ Blaine	% 28	34% ≥ No.325

* Chemical tests were made by the National Center for Geological Survey and Mines.

Table (2): Properties of fine aggregates *.

Sieve size (mm)	Cumulative passing 1 (%)	Limits of B.S. 882/1992 Over all grading	Cumulative passing 2 (%)	Limits of B.S. 882/1992 fine grading
4.75	95.2	89-100	100	-

2.36	78.6	60-100	100	80-100
1.18	52.0	30-100	100	70-100
0.60	24.3	15-100	100	55-100
0.30	10.9	5-70	59	5-70
0.15	3.8	0-15	13	-
SO_3 content = 0.28 % < 0.5 % limits of I.Q.S No.45/1984				

* Tests were made by the Concrete Laboratory in Karbala Technical Institute.

The steel fibers with a diameter of (200)µm and length of (13) mm (aspect ratio lf /df =65) were provided by Sika with a tensile strength of 1280 MPa and a density of (7820)kg/m3. According to ASTM C494-05, the used Sika ViscoCrete 5930 superplasticizer is classified as type F.

4. Experimental Program.

The shown concrete mix proportions in Table (3) were selected according to that mentioned by Ali [14]. To evaluate the compressive and splitting tensile strength at 28-day and 56-day, three concrete samples were chosen in each age. When the mixer filled with materials, the mixer was run for three min., resting for two min., and followed by remixing for three min.

Compression and splitting testing is performed on concrete cylinders that having dimensions of (20*10) cm. Making and curing of cylinders were done in accordance to (ASTM C 31/03). Capping were done according to (ASTM C 617-15) specifications using (Sika Grout 214 AE) for cylinders used in compression test. Testing the cylindrical specimens was done following both (ASTM C 39/04, and ASTM C 496-04). Testing is conducted at various ages, (28 and 56) day in order to observing the strength development with age. After that, (28) days was chosen because of most of the designers use this age in calculations and to make sure that mean target strengths were gained.

Table (3): Mix proportions.

Mix No.	Cement (kg/m^3)	Sand (kg/m^3)	SP by w.t of cement (%)	Gasification ash by w.t of cement (%)	Gasification ash by w.t of cement (kg/m^3)	w/c (%)	Steel fiber (%) V_f	Age (days)
M1	1100	1100	7	0	0	30	1	28 + 56
M2	1045	1100	7	5	55	30	1	
M3	990	1100	7	10	110	30	1	
M4	935	1100	7	15	165	30	1	
M5	880	1100	7	20	220	30	1	
M6	825	1100	7	25	275	30	1	

V_f = volume fraction of fibers (%) by vol. of concrete mix.

5. Durability Tests.

The freeze-thaw test was conducted in a MATEST rapid Freeze-thaw apparatus (Plate 1), which was provided with assistance from the Building and Construction Engineering Department at the University of Technology. This machine uses a freezer-plate beneath the specimen containers to cool the concrete, and electric heaters placed between the containers to warm the concrete. The rapid freeze-thaw procedure is standardized by (ASTM C666/03). The appropriate specimens were removed from the freeze-thaw machine after (25) and (50) cycles. Then, the specimens were removed during a thaw period, and stored at room temperature until testing.

Water cured specimens for (7) days were taken out and allowed to dry for three days and then the same concrete specimens were kept immersed in (2) and (4%) concentrated (according to literature) hydrochloric acid solution for (28) days for durability observation. The curing media was replaced with fresh solution at the end of every week to maintain the same concentration.

Plate (1): experimental setup: (a) freeze-thaw climatic chamber in the University of Technology.

6. Results and Discussion.

It is well known that the serviceability of any structural concrete element depend largely on its physical and mechanical properties. Further, appropriate making and curing of concrete produces a very dense mix that could resist the ingression of chemical substances and/or severe conditions. A major concern with gasification ash byproduct GA is how GA could alter the concrete properties in the hardened state. The concrete strength may be reduced or increased according to addition percent and testing age of the investigated mix.

Table(4) and Fig. (1 & 2) present the compressive strength data for all reactive powder concrete mixtures. These data show that gasification ash has a significant effect on the compressive strength of concrete mixtures up to (10%) of replacement. Free CaO can harm the volume stability and the concrete durability. The higher the GA replacement dosage the higher the CaO content. The data in Table (4) show that the (28) days compressive strengths of mixtures containing GA were larger than all other mixes except (M6) at (56) days. This enhancement was due to both pozzolanic activity and filling effect of GA in the matrix resulting in more dense and homogenous structure.

Table (4): Results of compressive strength (MPa).

Mix No.	28-day	56-day	Freezing & thawing		Acid attack	
			cycles 25	cycles 50	2 %	4 %
M1	87.3	95.2	52.8	47.6	72.6	64
M2	109.8	118.7	92	80.8	92	85.9
M3	116.7	128.4	100.4	89.1	95.4	93.5
M4	104	109.1	78.6	67.5	84	78.3
M5	96.8	99	70.9	60	76.1	65.8
M6	88.5	93.8	57.6	52.3	68.9	63.4

Results of compressive strength for (28) day specimens under freezing-thawing and acid attack confirm that dense matrix is the reason for higher residual compressive strength, as illustrated in Fig. (4 & 5). However, the control mix showed the lowest compressive strength, because it has no pozzolanic activity since no GA was added to mix. However, the residual strength for all mixes after being subjected to accelerated durability tests still higher than the minimum value (55) MPa for high strength concrete according to (ACI 363.2R-98) except (M6) subjected to (50) cycles of freezing and thawing.

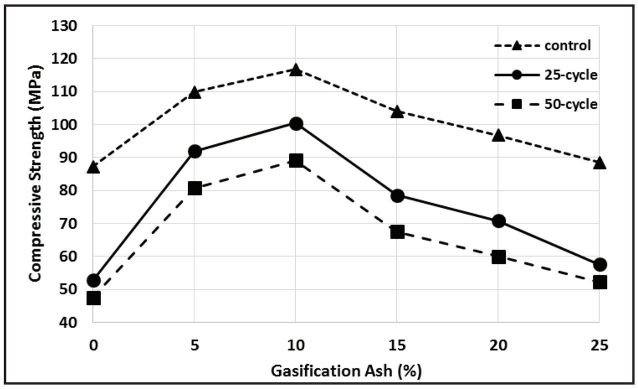

Fig. (1): Effect of gasification ash on compressive strength for (28) days samples exposed to freezing and thawing.

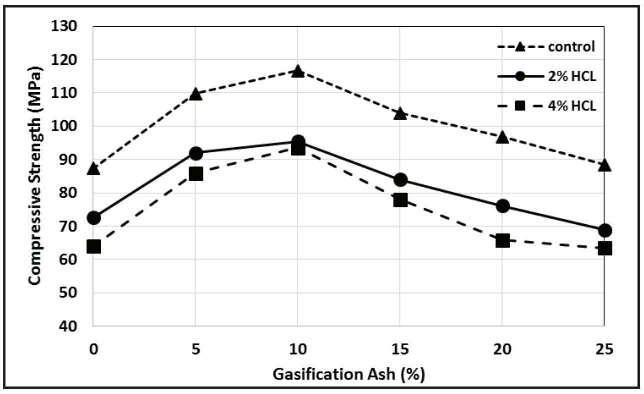

Fig.(2): Effect of gasification ash on compressive strength for (28) days samples exposed to acid attack.

After undergoing (25) cycles and then (50) cycles of accelerated aging of exposure to the environment of the freeze-thaw and (2%), (4%) HCl of acid attack, it was observed that saturated samples made with GA byproduct had higher strength values than control samples. This in agreement with [11 and 12], shows that the reactive powder concrete that contain GA byproduct is more suitable for use in hazard environments than that of control due to the filling effect of GA. Internal micro cracking without surface scaling, followed by loss in compressive strength of (14-39%) after (25) cycles and (23-50%) after (50) cycles of freezing and thawing were the main pronounced actions due to freezing and thawing.

The (28) days splitting tensile strength values for all batches are presented in Table (5) and Fig. (3 to 4). As in the case with concrete compressive strength, splitting tensile strength is heavily dependent on cementitious content and may be affected by dosing fresh concrete with GA byproduct. Data presented in Table (5) and Fig. (3 to 4) show that the splitting tensile strengths for mixtures containing GA were greater in all cases than control mix except for M6 at (28 and 56) days. Although, the variations between the reference and the GA samples are not high in most of the studied cases. As it expected, the (50) cycles of freezing-thawing exposure had the lower strength as compared to control. This is the same for (4%) concentration of HCl solution. This trend is similar to that found by Karthick M. and Nirmalkumar K [9].

Table (5): Results of splitting tensile strength (MPa).

Mix No.	28-days	56-days	Freezing & thawing		Acid attack	
			cycles 25	cycles 50	% 2	% 4
M1	9.2	9.6	4.8	3.5	3.7	3.4
M2	10.5	12.1	5.2	4.8	4.1	3.9
M3	12.2	13.4	6.3	5.9	5.3	5.4
M4	10.5	11.1	5.6	4.3	4.4	4.1
M5	9.2	9.5	4.9	3.9	3.1	2.8
M6	9.1	9.4	4.2	2.8	2.9	2.6

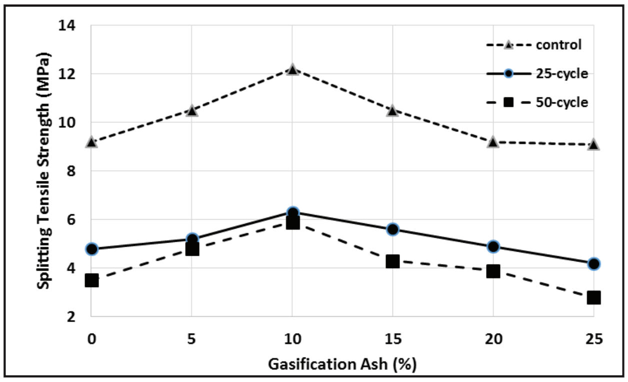

Fig.(3): Effect of gasification ash on splitting tensile strength for (28) days samples exposed to freezing and thawing.

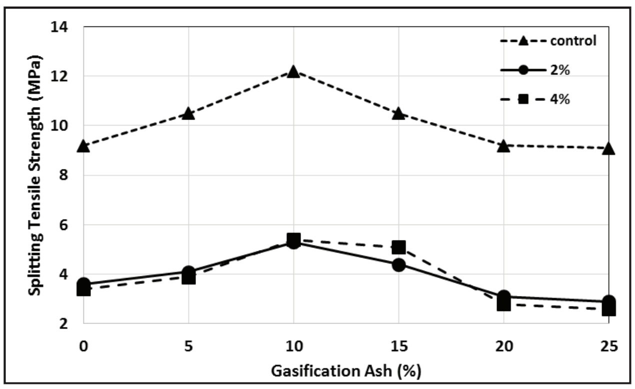

Fig.(4): Effect of gasification ash on splitting tensile strength for 28-days samples exposed to acid attack.

7. Conclusions.

Based on the analysis of data compiled throughout this research, the conclusions are summarized as follows: -

1. All mixes that contain GA byproduct had higher values of compressive and splitting strengths than that of control, which demonstrates that the GA byproduct could be used as supplementary cementitious material of not more than (10 %) of addition.
2. The inclusion of gasification ash into the RPC resulted in a good durability performance under the action of acid attack and freeze-thaw cycle.
3. Distress due to freezing and thawing action manifest in internal micro cracking without surface scaling, followed by loss in compressive strength of (14-39%) after (25) cycles and (23-50%) after 50 cycles of freezing and thawing.

4. Splitting tensile strength of RPC specimens experienced a maximum loss of about)68%(and (71%) due to exposure to (2%) HCl and (4%) HCl of acid attack respectively. However, this loss was not exceed (54%) and (59%) after the exposure to (25 and 50) cycles of freezing and thawing.

5. The deference in the strength development at (28 and 56) days lies between (3-10%) for all cases. This proves that (90%) of the ultimate strength of RPC gained at (28) days.

6. The exposure to high concentrations (i.e. 4 % HCl) have higher detrimental effect than those of lower concentrations.

References

[1] Bashandy A., "Influence of Elevated Temperatures on the Behavior of Economical Reactive Powder Concrete", Journal of Civil Engineering Research, Faculty of Engineering, Menoufiya University, Egypt, 3(3): 89-97, (2013).

[2] Kalifa H., Yahya O., Mohsen Y., "Effect of Calcined and Non Calcined Fly Ash Addition on The Strength of Concrete", Journal of Kerbala University, Vol. 13 No.1 Scientific. pp. 141-148, (2015).

[3] El-Louh O., "Fresh and Hardened Properties of Locally Produced Reactive Powder Concrete", Master degree thesis, The Islamic University Gaza, Civil Engineering Department, pp. 26, (2014).

[4] Kadhum M., "Studying of Some Mechanical Properties of Reactive Powder Concrete Using Local Materials", Journal of Engineering, Number 7, Volume 21, July pp. 113-135, (2015).

[5] Hassan M., "SEM-Backscattered Imaging analysis of Cementitious Composite Matrix Incorporating Mineral Admixture", Eng. &Tech. Journal, Vol. 32, Part (B), No.4, pp. 696-703, (2014).

[6] Agharde A. and Bhalchandra S., "Mechanical properties of reactive powder concrete by using fly ash", International Journal of Advanced Technology in Engineering and Science, Volume No.03, Issue No.01, January, pp. 603-608, (2015).

[7] Kumar M., Bivera B., Babu P. and Janagan S., "Effect of mineral admixtures on strength & durability of reactive powder concrete", Singaporean Journal of Scientific Research, Issue of International Journal of Applied Sciences, Vol.8, No.1, pp.58-70, (2016).

[8] Abdulabbas Z. "Utilization of Cement Kiln Dust in Concrete Manufacturing", Jordan Journal of Civil Engineering, Volume 7, No. 1, pp. 111-125, (2013).

[9] Karthick M. and Nirmalkumar K., "Durability Properties of High Strength Self Compacting Concrete using Silica Fume and Quarry Dust", International Journal of Scientific Engineering and Applied Science, Volume-2, Issue-4, April pp. 389-395, (2016).

[10] Solanki Y. and Pitroda J., "Investigation of Low Cost Concrete Using Industrial Waste as Supplementary Cementitious Materials", International Journal of Engineering Science and Innovative Technology, Volume 2, Issue 1, January pp. 81-88, (2013).

[11] Lee M., Lee G., Huang Y., and Lee K., "UHPC Precast Concrete under Severe Freeze-Thaw Conditions", International Journal of Engineering and Technology, Vol. 5, No. 4, August pp. 452-456, (2013).

[12] Jang S., Rokugo K., Park W. and Yun H., "Influence of Rapid Freeze-Thaw Cycling on the Mechanical Properties of Sustainable Strain-Hardening Cement Composite (2SHCC)", Materials Journal No.7, pp. 1422-1440,(2014).

[13] Beulah M., and Prahallada M. C.," Effect of Replacement of Cement by Metakaolin On the Properties of High Performance Concrete Subjected to Hydrochloric Acid Attack",

International Journal of Engineering Research and Applications, Vol. 2, Issue 6, November-December pp. 33-38, (2012).

[14] Ali I., "Optimal Strength Design of Reactive Powder Concrete", International Journal of Technical Research and Applications, Volume 5, Issue 1, pp. 5-12, (2017).