Comparison of different waste materials used as cement replacement in concrete

Talib Khalid W T, Obaidullah Qazi, Abdirizak A M*and Raizal S. M. Rashid
Housing Research Centre, Faculty of Engineering, University Putra Malaysia, 43400UPM
*cabdi860@gmail.com

Abstract. Among all the construction materials used in construction industry concrete is the most used one. With its main cementing ingredient being OPC But production of OPC comes at a cost both financial and environment that is why if OPC can be replaced to some extend by another material that is cheaper to produce than financial and environmental cost of concrete can be reduced significantly. Some industrial waste materials have cementing and pozzolanic properties thus they can used to replace cement in some proportion that will reduce the pollution as well as the cost that is caused by dumping of such materials. when used correctly such materials have positive impact on both fresh and hardened concrete such as increased strength, increased durability, higher workability, reduced permeability, higher resistance to acid attack and reduction of plastic shrinkage cracking therefore in this paper three industrial waste materials i.e. Fly ash, Silica fume and Ground Granulated Blast furnace slag are considered for their use as cement replacement materials. The mechanical properties were evaluated from the compressive Strength, while the durability was inspected in terms of chloride diffusion, permeability and at the same time Workability of concrete was also compared Use of such materials is both cost and environment friendly and these two words are seldom used together thus more public awareness and better standards are required for wide use of such waste materials in this regard

1. Introduction

Waste in general and Industrial waste in particular is one of the biggest dilemma of modern society as we develop according to this materialistic world view we create more stuff and thus create more waste. (World Bank Book, 2015) Disposal of industrial waste is a major problem for both developed and developing countries and it is becoming even a bigger issue for governments as awareness for environmental protection among general population increases

At the same time demand for high quality concrete is high because of rapid urbanization of developing countries and maintained of structures in developed countries. The demand for concrete will always be high as we need to repair and rebuilt structures all the time (World Cement & Concrete Additives) and concrete is one of the best materials for construction due to its flexibility and cost, so the question is not will be there demand for concrete but is the production of concrete sustainable with present practices and the answer is a big NO. And thus, making concrete with replacing some content
of cement with industrial waste can make production of concrete more sustainable as these replacement materials are already produces and will be discarded none the less

On the other hand properties of concrete have been shown to improve with the addition of discussed industrial waste material such as increased strength and workability to name a few (Liew, Sojobi and Zhang, 2017a)

With many advantages low quality of materials lack of awareness and lack or poor standards are still barriers for using these materials in construction industries.

1.1 Fly Ash
When pulverized coal is burned in coal powered power plants Fly ash is produced as a byproduct of that combustion and is collected from exhaust gases of such power plants (ASTM) Collection of Fly ash is mandatory in most parts of the world because in air it is a pollutant and causes respiratory and other health problems

Fly ash is classified now a days in two classes by ASTM depending on its chemical composition the classes are Class C and Class F and some class C fly ash which contain high calcium content are self-binding but those that do not have high alumina and silicon which act as pozzolanic agents.

As early as late 1930s (Raymond E. Davis, 1937) fly ash has been proposed for use in concrete as cement replacement as it contains silica and alumina salts and thus has pozzolanic properties use of fly ash has been recorded to increase strength and workability but. Materials used curing conditions and optimum production standards needs to be followed for its pozzolanic properties to be exploited properly. But at the same time fly ash concrete exhibit lower early age strength, longer setting time and lower resistance to deicing salts.

1.2 Silica fume
Silica fume or micro silica is a byproduct of the ferrosilicon manufacturing process which is collected from exhaust gases by condensers. The color of silica fume is either grey or white and their size is much smaller than the average size of cement particles. The aim of using silica fume as partial cement replacement is to gain high strength in the concrete. In the early 1950s they have tested silica fume in concrete and they have obtained high strength concrete, it’s also capable of reducing Permeability of the concrete and also its improving the resistance of the chloride ingress, it’s also better than Portland cement in sulfate environment.

1.3 Granulated blast furnace slag
According to ACI 116R GGBS is manufactured by heating the iron or steel in factory and GGBS is either in crystalline form which is used as aggregate in concrete or in glassy texture form which has Cementous properties and thus can be used as cement replacement materials. However, GGBS is consisted from four major constituents’ lime, silica, alumina and magnesia. Which similar the constituents of Portland cement but with different proportion.

When we utilize it in concrete Ground Granulated Furnace Blast Slag (GGBS). These materials are more reliable and valid for utilizing in concrete. It considers as replacement and alterations materials we can use it instead of cement in concrete.

This review paper briefly describes affected the proportion of GGBS on strength and durability of concrete. Replacement cement material use to increase the strength of the concrete as well as increase durability of concrete and also reduce temperature of hydration and higher the resistance for different attack such as sulfate attack, chloride attack.

2. Properties
Properties of concrete are affected by many factors and in real world the properties are always different than in lab as in real world the control over production is not as good as in lab (Paso, 2015)
Although all the properties have influence on the performance of structure but the most important ones are strength, durability and workability thus they are discussed below for Fly ash, Silica fume and GGBS.

Compressive test is one of the most important property of concrete as it is used to design structures and the higher the strength is the better the concrete is considered as with higher strength concrete the section of concrete used will be smaller thus reducing the cost of construction.

Durability is a very broad word and measuring durability by tests in a lab is not easy task but still there are some test that can be used to determine long term durability of concrete is important as structure is required to service well in future and with durability of concrete the maintenance and rebuilding of concrete structure will have a significant impact on long term budget.

Workability of concrete is very important as if concrete is not placed properly then it cannot attain its optimum strength and durability for a given mix, easier it is to place the concrete the better its performance in real world most of the discrepancies between real world performance of concrete and those made in lab are due to ill placement and improper compaction, and this issue is aggravated even further with low workability concretes.

2.1 Fly ash

2.1.1 Strength. On fly ash many Test have been conducted by many researchers, (Wang and Park, 2015), (Golewski, 2018), Grzegorz Ludwik (Nuruddin, Chang and Azmee, 2014)Chang, Kok Yung Azmee, Norzaireen Mohd regarding the strength of FA concrete and in all of them specimen containing FA has lower Early strength but higher later strength.

| Mix   | Age(days) | Strength f′cm (MPa) |
|-------|-----------|---------------------|
| FA-00 | 3         | 24.23               |
|       | 7         | 33.18               |
|       | 28        | 47.51               |
| FA-20 | 3         | 16.95               |
|       | 7         | 30.12               |
|       | 28        | 48.96               |
| FA-30 | 3         | 14.23               |
|       | 7         | 30.06               |
|       | 28        | 45.10               |

2.1.2 Durability. From tests such as chloride resistance test, porosity test, sorptivity test, and freezing and thawing test:

Chloride resistance test
This test for durability is important when discussing reinforced concrete and As per the result of test conducted containing high proportions of Sulfate ions and Free lime.
Freezing thawing
This test is performed to find durability of concrete in cold climate. Test conducted by Wang et al., 2017 zhi, Zhou Xiangming, Meng Yunfang, Chen, Zhen have shown addition of Fly ash makes concrete more resistant to freezing and thawing cycles

Permeability
Addition of fly ash has shown to decrease rate of hydration which in turn decrease drying shrinkage which in turn helps improves durability At the same time addition of fly ash has been attributed to lower sorptivity and porosity of concrete(Saha, 2017)
When Saha, (2017) conducted the microstructural morphology it showed improved density of binder matrix because of pozzolanic reaction

2.1.3 Workability. According to tests conducted by Yijin and Mukherjee workability of concrete is increased with the increase in FA content and this is attributed to the smaller size and higher specific surface area of FA particles as compared ordinary Portland cement Jing Yuab Cong Lua Christopher K.Y. GengyingLiac concluded that cementing efficiency is not effected by fly ash replacement when binder to water ratio was 0.2 and (Nuruddin, Chang and Azmee, 2014) also concluded from their data that in properly designed mix self-compaction of concrete can be achieved with fly ash as cement replacement in similar test by Alaka and Oyedele full workable Fly ash concrete was obtained at low water to binder ratio

2.2 Silica fume

2.2.1 Strength of SF. (Toutanji and El-Korhi, 1995) When silica fume is added to concrete, it's giving the concrete improvement on its compressive strength. This is because of enhance of pozzolanic activity

This chart illustrates different figures of compressive strength of concrete containing silica fume, as can be noticed from the chart above the strength of concrete is increased with the addition of Silica fume and this increase is attributed to pozzolonic nature of S.F in this experiment they used different
percentages of silica fume 5%, 7.5% and 10%. Concrete containing 7.5% of S.F has obtained the maximum strength of this experiment and it was 65.33 mpa for 28 days.

2.2.2 Durability of silica fume
   Permeability

Perraton et al. had tested the effect of silica fume on the permeability of the concrete made with 0.4 and 0.5 water cement ratio, the experiment had showed a decrease in chloride ion diffusion within the growth of silica fume. The positive thing about adding silica fume in the concrete is to diminish the capillary pores and increase in density.

Freezing and thawing

Some investigators imply that addition of silica fume improves the freeze-thaw resistance of the concrete. Cjorv (40) reported that the addition of 10% of silica fume by mass content and w/c of concrete was 0.36 and 0.37 with 1% of air, the experiment results exhibit that the concrete with silica fume has more durability than Portland cement.

2.2.3 Workability of silica fume. (‘Silica Fume 2.1 Introduction’, no date).
The rheology of concrete has been observed to stabilize with the addition of silica fume. Concrete containing silica fume is more cohesive and less prone to segregation than concrete without silica fume. Results have shown in the slump test that concrete with silica fume show lower slump than the normal concrete because of cohesiveness of the concrete mixture so it’s necessary to use two different slump test method to maintain the same apparent workability.

Using concrete containing silica fume has also shown a reduction in bleeding of the concrete because of high surface area to be wetted. JAHREN says this concrete needs to prevent early moisture loss and also to avoid plastic shrinkage in hot environments.

2.3 GGBS

2.3.1 Strength. The strength development of concrete containing GGBS takes longer as compared to ordinary Portland cement (OPC). Hydration of cement produces calcium hydroxide and it is exhausted by pozzolanic compounds. After 7 day the strength is greater than the control concrete. At about 55–59% is the range of optimum level of GGBS content for maximum strength. Reaction of GGBS results in lower early age strength but at final strength of such concrete is higher as compared to OPC. Chemical composition, physical properties are the reason of low strength. (Oner and Akyuz, 2007)

The compressive strength of concrete enhances when Cement is replaced by 40% GGBS for both M20 and M40 grade of concrete. Also the split tensile strength of concrete is enhanced when cement is replaced with GGBS. (Karri, Santosh Kumar, G. R. Rao, and P. Markandeya Raju).

Following is the data for test conducted by for M20 grade concrete

| % of GGBS | Compressive strength |
|-----------|----------------------|
|           | 7 days   | 28 days | 90 days |
| 0         | 33.3     | 46.2    |
| 30        | 35       | 50.11   |
| 40        | 36.42    | 52.49   |
| 50        | 32.2     | 48.12   |
2.3.2 Durability. Usage of slag as supplementary cementitious material will able to resist chemical attack, abrasion, or any other process of deterioration. The results shown GGBS improves the durability of concrete by reducing a pore size, so reduction in porosity of concrete, even at the early days of concrete age, therefore It is excellent against chemical attacks. It significantly prevents the ingress of sulfates. And the concrete with GGBS has diminished chloride penetration and it has been confirmed by many studies (Elahi et al., 2010).

AAS (alkali activate) mixture prepared with either 40% or 65% of GGBS, and mixed with water glass at two dosages 4% and 6% of Na2O by all weight of GGBS. Two types of water glass were used, the result indicated that alkali activation of GGBS results in smaller pore size in concrete and also ensures long term alkinity of concrete thus this prevents the corrosion of concrete. According to this experiment GGBS improve the durability of the concrete. (Al-Otaibi, 2008).

2.3.3 Workability. The concrete containing GGBS require less mix water from concrete without GGBS. The results have shown it improve the cohesiveness and workability of concrete. 55 percent of slag in concrete will increase the slump from 15mm to over 20mm. (Wainwright and Rey, 2000).

Comparison

Strength

All though ultimate compressive strength of all the concrete with industrial waste material was better than OPC the strength of silica fume was the highest followed by Fly ash and at last but not least was Ground granulated blast furnace slag

Durability

All the results for durability considered in this review show better durability of concrete as compared to normal OPC according to Liew, Sojobi and Zhang, (2017b) the following is the order for durability

Resistance to chloride penetration was highest for concrete reduced with Ground Granulated Blast furnace slag as replacement followed by Silica fume and Fly ash ASR mitigation was highest for Silica fume followed by fly ash and Ground Granulated blast furnace slag Resistance to sulphate attack was highest for Silica fume followed by Ground Granulated blast furnace slag

Workability

All the concrete made with Industrial waste as cement replacement material can be made workable easily at low w/b ratio with the use of superplasticizer although because of particle size difference Silica fume has the highest workability followed by Fly ash and GGBS in decreasing order

Conclusion

From our literature review we have concluded the following

1) the waste materials considered can be added in concrete to produce All ore favorable concrete i.e better strength, durability and workability
2) Whenever constructing a new project these waste materials should be considered
3) Addition of such waste materials does reduce the initial strength and thus more time for formwork is required
4) Type of waste material used should be selected based on the type of concrete needed and nearby availability of material
5) Use of such concrete can meet both structural and environmental requirement if implemented properly
6) As quality of waste material available cannot be standardized so proper lab testing should be carried out
References

[1] ASTM C618-92a. "Standard Specification for Fly Ash and Raw or Calcined Natural Pozzolan for Use as Mineral Admixture in Portland Cement Concrete," American Society for Testing and Materials, Annual Book of ASTM Standards, Volume 04.02, West Conshohocken, Pennsylvania, 199

[2] Raymond E. Davis, R. W. (1937). Properties Of Cements And Concretes Containing Fly Ash. ACI material journal, 577-612

[3] Al-Otaibi, S. (2008) ‘Durability of concrete incorporating GGBS activated by water-glass’, Construction and Building Materials, 22(10), pp. 2059–2067. doi: 10.1016/j.conbuildmat.2007.07.023.

[4] Elahi, A., Basheer, P. A. M., Nanukuttan, S. V. and Khan, Q. U. Z. (2010) ‘Mechanical and durability properties of high performance concretes containing supplementary cementitious materials’, Construction and Building Materials. Elsevier Ltd, 24(3), pp. 292–299. doi: 10.1016/j.conbuildmat.2009.08.045.

[5] Golewski, G. L. (2018) ‘Green concrete composite incorporating fly ash with high strength and fracture toughness’, Journal of Cleaner Production. Elsevier B.V., 172, pp. 218–226. doi: 10.1016/j.jclepro.2017.10.065.

[6] Liew, K. M., Sojobi, A. O. and Zhang, L. W. (2017a) ‘Green concrete : Prospects and challenges’, Construction and Building Materials. Elsevier Ltd, 156, pp. 1063–1095. doi: 10.1016/j.conbuildmat.2017.09.008.

[7] Liew, K. M., Sojobi, A. O. and Zhang, L. W. (2017b) ‘Green concrete : Prospects and challenges’, Construction and Building Materials. Elsevier Ltd, 156, pp. 1063–1095. doi: 10.1016/j.conbuildmat.2017.09.008.

[8] Nuruddin, M. F., Chang, K. Y. and Azmee, N. M. (2014) ‘Workability and compressive strength of ductile self compacting concrete ( DSCC ) with various cement replacement materials’, Construction and Building Materials. Elsevier Ltd, 55, pp. 153–157. doi: 10.1016/j.conbuildmat.2013.12.094.

[9] Oner, A. and Akyuz, S. (2007) ‘An experimental study on optimum usage of GGBS for the compressive strength of concrete’, Cement and Concrete Composites, 29(6), pp. 505–514. doi: 10.1016/j.cemconcomp.2007.01.001.

[10] Paso, E. (2015) ‘Comparison of Field and Laboratory Strengths of Concrete Slabs’, (June).

[11] Saha, A. K. (2017) ‘SC’, Sustainable Environment Research. the Chinese Institute of Environmental Engineering, Taiwan. doi: 10.1016/j.serj.2017.09.001.

[12] ‘Silica Fume 2.1 Introduction’ (no date). doi: 10.1007/978-3-642-17866-5_2.

[13] Toutanji, H. A. and El-Korchi, T. (1995) ‘THE INFLUENCE OF SILICA FUME ON THE COMPRESSIVE STRENGTH OF CEMENT PASTE AND MORTAR’, cement and Concrete Research, 25(7), pp. 1591–1602.

[14] Wainwright, P. J. and Rey, N. (2000) ‘Wainwright, P.,and Rey, N., “ The influence of ground granulated blastfurnace slag (GGBS) additions and time delay on the bleeding of concrete”. Cement and Concrete Composites, 22(4), pp.253-257, 2000.’, 22, pp. 253–257. doi: 10.1017/CBO9781107415324.004.

[15] Wang, D., Zhou, X., Meng, Y. and Chen, Z. (2017) ‘Durability of concrete containing fly ash and silica fume against combined freezing-thawing and sulfate attack’, Construction and Building Materials. Elsevier Ltd, 147, pp. 398–406. doi: 10.1016/j.conbuildmat.2017.04.172.

[16] Wang, X. and Park, K. (2015) ‘Analysis of compressive strength development of concrete containing high volume fly ash’, CONSTRUCTION & BUILDING MATERIALS. Elsevier Ltd, 98, pp. 810–819. doi: 10.1016/j.conbuildmat.2015.08.099.

[17] World Bank Book (2015) Waste Generation.

[18] Jabbar, S., Hejazi, F., & Mahmoud, H. M. (2016). Effect of an Opening on Reinforced Concrete Hollow Beam Web Under Torsional, Flexural, and Cyclic Loadings. Latin American Journal of
[19] Perraton, D., Aitcinmm, P.C., Vezina, D.: Permeabilities of silica fume concretes. ACI Special Publications SP-108, pp. 63–84 (1988)

[20] Demand and Sales Forecasts, Market Share, Market Size, Market Leaders. World Cement & Concrete Additives - Demand and Sales Forecasts, Market Share, Market Size, Market Leaders, www.freedoniagroup.com/World-Cement-Concrete-Additives.html.

[21] Karri, Santosh Kumar, G. R. Rao, and P. Markandeya Raju. (2015). "Strength and Durability Studies on GGBS Concrete." SSRG International Journal of Civil Engineering (SSRG-IJCE) 2.10 34-

[22] Hejazi, F., Ostovar, N., & Bashir, A. (2017, July). Seismic Response of Shear Wall with Viscous Damping System. In Global Civil Engineering Conference (pp. 595-607). Springer, Singapore.

[23] L. Yijin, Z. Shiqiong, Y. Jian, G. Yingli, The effect of fly ash on the fluidity of cement paste, mortar, and concrete, in: International workshop on Sustainable Development and Concrete Technology, Beijing, China, 2004, pp. 339–345.

[24] Pradhan, B. (Ed.). (2018). GCEC 2017: Proceedings of the 1st Global Civil Engineering Conference (Vol. 9). Springer.