doi:10.4028/www.scientific.net/KEM.594-595.465

An Overview of Fly Ash and Bottom Ash Replacement in Self Compaction Concrete

Aeslina Abdul Kadir[1, a], Mohd Ikhmal Haqeem Hassan[2, b]

[1, 2]Faculty of Civil and Environmental Engineering,

Universiti Tun Hussein Onn Malaysia (UTHM),

86400 Parit Raja, Batu Pahat Johor, Malaysia

(Corresponding email: [a] aeslina@uthm.edu.my, [b] mohd.ikhmal.haqeem@gmail.com)

Keywords: Self Compaction Concrete; Fly Ash; Bottom Ash; Waste products; Building materials

Abstract. Over the centuries, concrete is commonly been used in construction world due to its properties. From the conventional concrete until the concrete that has been diversify with innovations, the usefulness is still the same, which is as building materials. One of the innovations called Self-Compaction Concrete (SCC). SCC is a type of concrete that does not require any mechanical compaction at all. This type of concrete will leveled and compacted under its self-weight. Such concrete will accelerate the placement, reduce the labor requirements needed for consolidation, finishing and eliminate environmental pollution. In terms of sustainability, previous researchers have recycled so many waste in SCC for example coal ash, silica fume, hydraulic lime, rice husk ash and fine limestone powder. Recently, recycling fly ash and bottom ash in SCC has grasped the attention of researchers as it demonstrated promising results. Furthermore, previous investigations already confirmed the potential of fly ash and bottom ash in replacing aggregates in SCC represents a better option than landfill and at the same time will decrease pollution problem especially in coal combustion area. This paper reviews the fly ash and bottom ash replacement in SCC.

Introduction

Concrete was first used as a building material as early as the 1850's. It is one of the most common materials that are used in building construction industry. It consists of a hard, chemically inert particulate substance, known as an aggregate which is usually made from different types of sand and gravel, which is bonded together by cement and water. Concrete can be readily moulded into virtually any required shape compared to other materials. Due to its flexibility, concrete is the preferred construction material for a wide range of buildings, bridges and civil engineering structures [1].

A recent innovation in concrete technology called Self Compaction Concrete (SCC), has numerous advantages over normal concrete. Self-compaction concrete, as the name indicates, is a type of concrete that does not require any mechanical compaction, because it will level and compact under its own self-weight. Such concrete will accelerate the placement, reduce the labor requirements needed for consolidation, finishing and eliminate environmental pollution. SCC can spread and fill every corner of the formwork, purely by means of its self-weight, thus eliminating the need of vibration or any type of compacting effort at all [2]. SCC also can be describe as high performance material that flows under its own weight without demand for vibrators to achieve consolidation by complete filling formworks even when access is hindered by narrow gaps between reinforcement bars [3].

At the beginning, Professor Hajime Okamura was discovered SCC in Japan since the late 1980's. Then early prototype has developed in 1988 as a response to the growing problems associated with concrete durability, the high demand for skilled workers and to been applied for highly congested reinforced structures in seismic regions [4]. Since that, SCC has been widely used in large construction in Japan and the usages are gradually increases all over the world [5].

The main reasons for the employment of SCC are to shorten construction period, to assure compaction in the structure and to eliminate noise due to vibration.

Furthermore, SCC can also been considered as the most revolutionary development in concrete construction for several decades. It has proved beneficial economically because of a number of factors such as providing faster construction, reduction in site manpower, easier placing and implementation, greater freedom in design and produce better surface of finishes. The usage of SCC could improved the durability of concrete, reduced noised level due to absence of vibration and give uniformity when casting [6,7].

Due to the demand and advantages of SCC and moving towards sustainability, many attempts have been made to incorporate waste in the production of SCC including coal ash, silica fume, hydraulic lime, rice husk ash, fine limestone powder and other similar additives. Recycling the wastes by incorporating them into SCC is a practical solution to pollution problem. The utilisation of wastes in SCC usually has positive effects on the properties, although the decrease in performance in certain aspects has also been observed. Recently, fly ash and bottom ash are one of the most potential wastes to be recycled into SCC. A wide range of successfully recycled fly ash and bottom ash and their effect on the physical and mechanical properties of SCC have been discussed in detail. Most of the recycled waste demonstrated both advantages and disadvantages in the SCC manufacturing process. Therefore, in this review, fly ash and bottom ash used in SCC were described according to the researchers.

Fly Ash and Bottom Ash

Fly ash and bottom ash are one kind of waste product in the coal-fired power plants, which contains large quantities of toxic metals, including mercury and arsenic. The combustion of coal after been heated at specific temperatures and pressures in power stations produces ash. The fraction of fly ash carried upwards with the flue gases and captured before reaching the atmosphere by highly efficient electrostatic precipitators. This type of materials called as fly ash. It is consist mainly of fine, glassy spheres and looks similar to cement. Beside that, the coarse ash fraction that falls into the grates below the boilers, where it is mix with water and pumped to lagoons called as bottom ash and it has gritty texture. This coal bottom ash is physically coarse, porous, glassy, granular, grayish and incombustible materials that are collected from the bottom of furnaces that burn coal. The type of bottom ash produced depends on the type of furnace and the sources of coal [8]. It also mentioned that from the burning process of coal, 80% of product will become fly ash and remain 20% of product is bottom ash. The production of fly ash and bottom ash from coal fired electric power plants; generate tons of combustion waste every year, mostly lightweight fly ash and heavier bottom ash that settles on the floor of the boilers and the bulk of this ash goes straight to landfills. The disposal process of fly ash and bottom ash at the power station is quickly becoming obsolete and utilities are spending hundreds of millions of dollars to engineer safer and stronger landfill for coal combustion products that are unable to been used beneficially. Thus, the initiative to promote the reuse of coal combustion waste is significant as the growing amount of the by-product material produced each year. The usage of waste material such as fly ash and bottom ash also could been seen as a brilliant way to minimize the use of natural sources for fine aggregate in concrete as well as preventing pollution.

In general, the usage of fly ash is more prevalent compared to bottom ash. In the modern concrete, fly ash could act as active mineral additives and been used as the essential component that provides concrete with higher compressive strength, great fluidity, and higher durability. Fly ash that produced during combustion of coal often used to supplement Portland cement in concrete production. Ash that has been use as a cement replacement must meet certain construction standards such as 75% of the ash must have fineness of 45 μm or less. Fly ash concrete consisting mostly of silica, alumina and iron and it is a pozzolan--a substance containing aluminous and siliceous material that forms cement in the presence of water. When mixed with lime and water it forms a compound similar to Portland cement. Moreover, this waste material also improved the workability of concrete mix due to its spherical shaped particles of fly ash that will act as miniature ball bearings within the concrete mix, hence providing a lubricant effect. Higher fly ash contents will yield higher water reductions and the decreased water demand has little or no effect on drying shrinkage/cracking. Apart from replacing cement with the same amount of fly ash can reduce the heat of hydration of concrete; this reduction does not sacrifice long-term strength gain or durability. The reduced heat of hydration lessens heat rise problems in mass concrete placements. Hence, the use of fly ash been accepted in recent years primarily due to saving cement, consuming industrial waste and making durable materials, especially due to the improvement in the quality stabilization of fly ash.

For bottom ash, the highest compressive strength obtained for all mixture is when the bottom of the coal ash alone only used in 15% replacement of fine aggregate in SCC. There were several other researches investigate the mechanical properties of the concrete made with coal bottom ash has been conducted by Abdulhameed and Khairul [9] and Muhardi et al [10] in conventional concrete mix. The results show that bottom ash give the same compressive strength of conventional concrete and found that the compressive strength of both bottom ashes concrete increased when silica fume was added to the mixture. The advantage of bottom ash is that, unlike sand, it has some cementitious properties and there is possibility that the strength to be slightly higher, more durable compared with the conventional concrete. Thus, from the previous research, fly ash and bottom ash demonstrated a promising potential as an inert in the concrete. Therefore, this paper reviews the fly ash and bottom ash replacement in SCC.

Overview of Fly Ash and Bottom Ash Replacement in SCC

The growth of SCC has been one of the most substantial developments in the building industry and utilizing fly ash and bottom ash are substantial due to the restrictive environmental regulations. Moving towards sustainability, many researchers are encouraged and had utilized fly ash and bottom ash into SCC. Mehta [11] and Neville [12] have suggested a simple approach of increasing the sand content and reducing coarse aggregate content by 4% to 5% to avoid segregation. High flowability requirement of SCC leads to the use of mineral admixtures such as coal fly ash in its manufacturing. Spherical fly ash particles contribute to lower friction during flow of the mortar fraction in the concrete. Use of mineral admixtures such as fly ash, and other similar fine powder additives, increases the fine materials in the concrete mixture [5]. The combination of one or more mineral additives with different morphology and grain-size distribution can improve particle-packing density and reduce inter-particle friction and viscosity. Hence, it improves deformability, self-compatibility, and stability of the SCC.

From a laboratory test result that has been reported by Naik et al [13] that used four different mixture:SC1, control mixture without fly ash while other mixtures SC2, SC3, and SC4 contained Class C fly ash at 35%, 45%, and 55% of replacement by mass. The results obtained shows that the use of high-volumes of Class C fly ash replacement in SCC significantly reduces the requirements of super plasticizer as well as the viscosity-modifying agent. This indicates that, it is possible to manufacture economical SCC by using high-volumes of Class C fly ash. The replacement of fly ash also perpetuates the desired 28-day strength of about 48 MPa or higher. In a similar study by Yahia et al [14] also reported that the dosages of super plasticizer reduced by using mineral additives in SCC.

Prajapati et al [15] also reviewed the study on fly ash. Initial mix design carried out to form S40-fo at coarse aggregate content of 30% by volume of concrete and fine aggregate content of 50% by volume of mortar in concrete and cement 480kg/m^3. The water/binder (W/b) used is ratio constant of 0.40 (by weight). The dosage of super plasticizer w estimated to be 2.7 % of powder content (cement, fly ash). Then, 10%, 20% and 30% by weight of cement replaced by equal weight such as 10%, 20% and 30% of fly ash respectively. In addition, S40-f10, S40-f-20, S40-f30 of SCC has prepared which satisfied rheological properties. Dosages of super plasticizer used as required according to slump flow. The properties of SCC mixed with fly ash concluded that the addition of fly ash in mix increases the filling and passing ability of concrete, whereas super plasticizer imparts workability to concrete improving segregation resistance of concrete. Addition of fly ash in the mixture resulted in reduction of super plasticizer for a similar workability (flow diameter). Furthermore, as expected, for similar workability, increasing the W/b ratio reduces the amount of super plasticizer required. The addition of fly ash will help to increase fluidity of the concrete because fly ash particles are spherical which is helpful to gain workability and cohesiveness [16, 17].

On the other hand, Bouzoubaa and Lachemi [18] examined the properties of SCC incorporating high volumes of class F fly ash. In this experimental works, there were nine SCC mixtures and one control concrete has been casted. The content of cementitious material has maintained constant 400 kg/m³ while the W/b ratios ranged from 0.35 to 0.45. The self-compacting mixtures had a cement replacement of 40%, 50% and 60% by class F fly ash. It shows that the compressive strength at 28-day of the concrete ranging from 26 to 48 MPa which could be an economical alternative to developed SCC incorporating with high volumes of class F fly ash. The well-known beneficial advantages of using fly ash in concrete such as improved rheological properties and reduced cracking of concrete due to the reduced heat of hydration of concrete demonstrated in SCC by utilization of fly ash as filler [4].

According to Siddique [19], large size (greater than 6mm) bottom ash can being used as coarse aggregate. In addition, the small size can be use as fine aggregate. The strength properties test conducted. The results observed has demonstrated significant improvement in the strength of concrete by the addition of class F fly ash as partial replacement and can be efficiently used in structural concrete. Then Siddique et al [20] studied the influence of water/powder ratio on strength properties of SCC containing coal fly ash and bottom ash. The results obtained shown similar behavior to normal SCC by increasing the strength through decreasing the water–powder (W/p) ratio. A comparison between SCC with various fly ash contents and replacements of fine aggregates and bottom ash investigated. The results indicated that SCC strength increased with the decreasing of W/p from 0.439 to 0.414 for 0% bottom ash, 0.50–0.47 for 10% bottom ash, 0.58–0.51 for 20% bottom ash and 0.620–0.546 for 30% bottom ash. By containing 15% and 35% of fly ash mixes exhibited strength of 60 MPa and 40 MPa, respectively at 90 days. Therefore, it was possible to produce SCC with a compressive strength of 40 to 50 MPa with 15% to 35% fly ash replacement.

As for Kurama et al [21], the researcher discussed about recycling bottom ash in construction is restricted as follows; the ash has angular structural characteristics, contains unburned carbon particles. In this research, the strength and drying shrinkage of concretes with furnace bottom ash (FBA) as sand replacement at 0%, 30%, 50%, 70% and 100% by mass, were studied at fixed water–cement ratios and fixed slump ranges [22]. The results showed that, at fixed W/b ratios, the compressive strength and the drying shrinkage decreased with the increase of the FBA sand content.

Kasemchaisiri et al [23] also conducted the experimental works on mechanical properties of SCC incorporating with bottom ash as partial sand replacement of 10%, 20% and 30% by weight. Mix proportion of the investigated powder-typed SCC was determined by fixing the water to powder ratio at 0.31. The experimental showed that slump flow and L-box passing ability of the SCC mixtures with lower bottom ash replacement, whilst 500-mm slump flow time (T500) increased with the increased of bottom ash replacement level. Bottom ash usage resulted in the reduction of compressive strength and caused increase in porosity of hardened concrete. However, 10% replacement by weight of total fine aggregate showed a better durability, chloride penetration, carbonation depth and drying shrinkage compare to control SCC mix.

Conclusion

As a conclusion, based on the literature review, a positive contribution by utilization of fly ash in SCC is higher compressive strength with low water content, reducing the amount of super plasticizer used during manufacturing and more durable structures. The compressive strength of SCC that used bottom ash as fine aggregate was recorded higher. Besides, bottom ash contained some cementitious properties and there is possibility that the strength to be slightly higher, more durable compared with the conventional concrete. In order to get the better result of SCC that combined with these waste materials, an appropriate mix proportions and procedure is essential for widespread use in SCC to obtained better properties. Future research on the replacement of fly ash and bottom ash in SCC should focus on the effect of durability and strength properties. The establishment of standards that spells out guidelines on its usage also should carried out. Application of these waste products as replacement will not only help to achieve economical mixture, but it can enhance the properties and consequently the durability of SCC.

Acknowledgement

Firstly, I would like to express my gratitude to head of researcher, Dr. Aeslina Abdul Kadir for the valuable guidance and advice. All advised and help either academically or non-academically are useful and will never been forgotten. Special thanks to Office for Research, Innovation, Commercialization and Consultancy Management (ORICC) that guide me to handle this research properly. Finally, an honorable mention goes to my family and friends for their understandings and supports on me in completing this project.

References

[1] Frank Robert Altobelli, “An Innovative Technology in Concrete Construction”, 1989.

[2] K. H. Khayat and Z. Guizani, “Use of Viscosity-Modifying Admixture to Enhance Stability of Fluid Concrete”, *ACI Materials Journal*, Vol. 94, No. 4, 1997, pp. 332-341.

[3] Zhu W., Bartos P.J.M, “Permeation properties of self-compacting concrete”. Cement and Concrete Research, Vol. 33, 2003, pp. 921-926.

[4] Okamura H., Ouchi M., “Self-Compacting concrete, Journal of Advanced Concrete Technology” Vol: 1(1), 2003, pp 5-15.

[5] Okamura H., Ouchi M., “Applications of self-compacting concrete in Japan”, The 3rd International Rilem Symposium on Self-Compacting Concrete. Wallevik OH, Nielson I, editors RILEM Publications A.R.L., Bagneux, France,2003, pp. 3-5.

[6] EFNARC, “Specifications and Guidelines for Self-Compacting Concrete”, (www.efnarc.org), 2002, pp 1-32.

[7] Krieg W, “Self-Compacting Concrete: Definition, Development and Applications”, A technical Paper Presented in the Meeting of ACI, Saudi Arabia Chapter, Eastern Province, October, 2003.

[8] Mohd Syahrul Hisyam Mohd Sani, Fadhluhartini bt Muftah, Zulkifli Muda, “The Properties of Special Concrete Using Washed Bottom Ash (WBA) as Partial Sand Replacement”, International Journal of Sustainable Construction Engineering & Technology Vol. 1, No 2, December 2010.

[9] U. A. Abdulhameed and S.B. Khairul (2012), “Properties of concrete using Tanjung Bin Power Plant coal bottom ash and fly ash”, International Journal of Sustainable Construction Engineering and Technology, Vol. 3(2): 56-69, 2010.

[10] Muhardi, Marto, A., Kassim, K. A., Makhtar, A. M., Lee F. W. and Yap S. L. “Engineering Characteristics of Tanjung Bin Coal Ash”, Electronic Journal of Geotechnical Engineering, Vol. 15: 1117-1129.

[11] Mehta PK, “Concrete structure: properties and materials”,NJ, USA: Prentice-Hall, 1986.

[12] A. M. Neville, “Properties of Concrete” Fourth Edition, Longman Group Limited, P.757- 758, 1995.

[13] Naik T.R., Kumar R., Ramme B.W., Fethullah Canpolat, “Development of high-strength, economical self-consolidating concrete”, Construction and Building Materials 30 (2012) 463–469.

[14] Yahia A., Tanimura M., Shimabukuro A., Shimoyama Y., "Effect of rheological parameter on self-compactability of concrete containing various mineral admixtures", RILEM international symposium on self-compacting concrete, Stockholm, Sweden, September; 1999, p. 523–35.

[15] Prajapati Krishnapal, Chandak Rajeev and Dubey Sanjay Kumar, "Development and Properties of Self Compacting Concrete Mixed with Fly Ash", Research Journal of Engineering Sciences Vol. 1(3), 11-14, Sept. 2012.

[16] Naik T.R., Kumar R., "Use of limestone quarry and other by-products for developing economical self-compacting concrete", Report CBU 2003-15, UWM center for by-production utilization, University of Wisconsin –Milwaukee, USA, April 2003.

[17] Naik T.R., Ramme B.W., " High –strength of concrete containing large quantities of fly ash", ACI Mater J, 86 (2),1989, 111 - 6.

[18] N. Bouzoubaa and M. Lachemi, " Self Compacting Concrete Incorporating High- Volumes of Class F Fly Ash: Preliminary Results", Cement and Concrete Research, Vol. 31, No. 3, March 2001, pp. 413-420.

[19] Siddique R., "Utilization of coal combustion by-products in Sustainable Construction materials, resources, conservation and recycling, Vol. 54, Issue 12, 2010, pp. 1060-1066.

[20] Siddique R., Paratibha Aggarwal, Yogesh Aggarwal, "Influence of water/powder ratio on strength properties of self-compacting concrete containing coal fly ash and bottom ash", Construction and Building Materials 29 (2012) 73–81.

[21] Kurama H. and Kaya M., "Usage of Coal Combustion bottom ash in concrete mixture" Construction and Building Materials, Vol. 22, 2008, pp. 1922-1928.

[22] Bai Y, Darcy F. & Basheer P.A.M. (2005), "Strength and drying shrinkage properties of concrete containing furnace bottom ash as fine aggregate", Construction and Building Materials 19, 2005, 691–697.

[23] Kasemchaisiri R. and Tangtermsirikul S., "Properties of Self- Compacting Concrete in Corporating Bottom Ash as a Partial Replacement of Fine Aggregate" Science Asia, No 34, 2008, pp 087-095.

[24] X. G. Li, Y. Lv, B. G. Ma, Q. B. Chen, X. B. Yin, S. W. Jian., "Utilization of municipal solid waste incineration bottom ash in blended cement", Journal of Cleaner Production, Volume 32, September 2012, Pages 96-100.

[25] J. Yao, W. B. Li, Q. N. Kong, Y. Y. Wu, R. He, D. S. Shen, "Content, mobility and transfer behavior of heavy metals in MSWI bottom ash in Zhejiang province, China", Fuel, Volume 89, Issue 3, March 2010, Pages 616-622.

[26] Y. Wei, T. Shimaoka, A. Saffarzadeh, F. Takahashi, "Mineralogical characterization of municipal solid waste incineration bottom ash with an emphasis on heavy metal-bearing phases", Journal of Hazardous Materials, Volume 187, Issues 1–3, 15 March 2011, Pages 534-543.