Ash Development Association of Australia

FLY ASH TECHNICAL NOTE NO. 11

2012

USE OF FLY ASH TO ACHIEVE ENHANCED SUSTAINABILITY IN CONSTRUCTION

INTRODUCTION

Sustainability of our built environment has become one of the most promiment considerations in building design and construction. The definitions for sustainability itself take different forms and how sustainability may be rated is currently a developing science[1,2,3]. There are many rating systems that have been developed to measure environmental impact and drive sustainable development, one example being Green Star rating tools published by the Green Building Council of Australia (GBCA)[4].

This technical note has been produced by the Ash Development Association of Australia to provide guidance to architechs, designers, engineers, contructors and infrustructure owners in understanding how best to use fly ash to achieve enhanced sustainbility in construction.

The environmental impact of using concrete, the most commonly used construction material worldwide, is being debated along with its consitutent materials in research and industry spheres. Fly ash, being a by-product of coal fired electricity generation situated across Australia, has played a key role in this debate over the past 30 years and can potentially provide future solutions to problems faced on building and infrastructure projects when applied and used properly.

The use of fly ash as a supplementary cementitious material (SCM) in concrete is well recognised for its economic and performance advantages including improved workability, mix efficiency and durability[5,6,7]. Fly ash is also widely recognised, used and specified in standards covering SCMs[8] and General Purpose and Blended Cements[9]. More recently, the focus for the use of fly ash in concrete has shifted to quantifying benefits offered in enhancing concrete sustainability[10]. This Technical Note details the benefits fly ash can provide in producing sustainable concrete and how cement replacement with byproducts such as fly ash can directly contribute to sustainable development whilst maintaining other criteria including:-

- Engineering design aspects;
- Constructional aspects; and
- Economic advantages.

WHAT IS SUSTAINABLE DEVELOPMENT?

Sustainable development can be generally defined as development that meets the needs of the present without compromising the ability of future generations to meet their own needs[11]. It can be broken down into three components – environmental, economic and social[12,13]. Sustainability is said to be achieved when all three components are satisfied.

Concrete has a relatively low embodied energy when compared with other construction materials. It is a high quality, low cost material which is flexible, practical and durable and thus used extensively in construction. Used in such abundance worldwide,

its impact on sustainability when considered wholistically can be significant. There is currently significant debate regarding appropriate assessment criteria for measuring environmental impact in the use of concrete and component materials[14,15,16]. Key elements that could be considered to result in a more sustainable outcome when using concrete are:-

- Resource depletion,
- Emissions to air in the production of the material (or component materials (embodied energy),
- Water consumption, and
- Waste avoidance and reduction.

Fly ash has been proven to have a lower embodied energy compared with hydraulic cement as defined in AS3972[9,17,18]. Appropriate design and contruction considerations must be undertaken when using fly ash to exploit the lower embodied energy benefits and technical properties to achieve the required design and construction criteria. These issues are discussed in some detail in the Ash Development Association of Australia Technical Note 8[7].

GREEN STAR AND HOW TO ACHIEVE CREDITS

Green Star is a national, voluntary environmental rating system that evaluates the environmental design and construction of buildings[4]. It covers different categories that assess environmental impact, including the materials category which is further divided into different material credits. The concrete materials credit awards up to 3 points for the use of sustainable concrete[19]. The purpose of the credit is designed “to encourage and recognise the reduction in greenhouse gas emissions, resource use and waste impacts associated with the use of concrete”. The Mat-5 concrete credit was recently revised by the GBCA and with respect to cement replacement it awards 1 point where the cement content is reduced by 30% or 2 points where it is reduced by 40% for all concrete used in a project. Cement replacement with fly ash can therefore directly translate to Green Star credits if the use of fly ash results in this criteria being met. To evaluate reduction levels, Reference Case Portland cement contents for different strength grades are nominated in the credit[18].

THE BENEFITS OF USING FLY ASH FOR SUSTAINABLE CONCRETE

In the published technical literature some of the effective strategies to produce more sustainable concrete is to replace a portion of the cement conponent with one or more SCMs such as fly ash[7,12,16]. The benefits of the use of fly ash towards more sustainable construction materials include:-

- Reduction in CO_2 emissions and embodied energy;
- Reduction in resource use;
- Reuse of industrial by-products as alternative raw materials; and
- Sustainability achieved through efficient design and enhanced durability.

Reduction in CO_2 Emissions

The manufacture of Portland Cement is an energy intensive process that releases approximately 0.820 tonne of CO_2 emissions for each tonne of cement produced[16]. In a standard concrete mix, the cement component commonly accounts for approximately 70% to 80% of the embodied energy. Fly ash, being a by-product of coal fired electricity generation, has a relatively low embodied CO_2 content related to its manufacture, estimated at 0.027kg of CO_2 emissions per tonne,[10,16,20] that is, 3% that of Portland cement manufacture. In order to better illustrate the benefit of fly ash in CO_2 emission reduction, a comparison of CO_2 emissions for typical 25 MPa and 50MPa concrete mixes with increasing proportions of fly ash are presented in Figures 1 and 2 repsectively (following references 17, 20 and 21). The result are also summarised in Table 1 to the right.

Reducing the cement content in concrete by incorporation of SCMs such as fly ash is arguably the most efficient and economical means of reducing CO_2 emissions and embodied energy of concrete. Though care is needed when undertaking this to ensure that other engineering design and constructional requirements are maintained as detailed in ADAA Technical Note 8 and other industry guides[6,7]. Other benefits of using fly ash, such as reducing water demand in concrete for particular workability requirements, can be factored in when using fly ash in concrete. For example recent research on post-tensioned slabs in buildings[21] and on pretensioned bridge girders[22] has shown that simple reduction of Portland cement in concrete does not necessarily result in lowering embodied energy of the structural element. The ADAA has published additional details in ADAA Reference Data Sheet 9[23]. Through efficient design, established structural and constructional performance criteria can be met along with achievement of reduced element embodied energy. Fly ash inclusions in the concrete enhance such solutions for structural, constructional and environmental benefit[20,21].

Typical Concret Mix Details	CO2 emissions (tCO_2-e/m^3)			
	GBCA Reference Case Portland Cement Mix	25% Fly Ash mix	30% Fly Ash mix	40% Fly Ash mix
Typical 25MPa mix	0.307	0.245	0.239	0.216
Reduction in CO_2 emissions for 25MPa mix compared to GBCA Reference Case (%)		19%	27%	38%
Typical 50MPa mix	0.496	0.385	0.365	0.324
Reduction in CO_2 emissions for 50MPa mix compared to GBCA Reference Case (%)		21%	32%	44%

Table 1: Summary of CO_2 emission reductions achievable with the use of Fly Ash

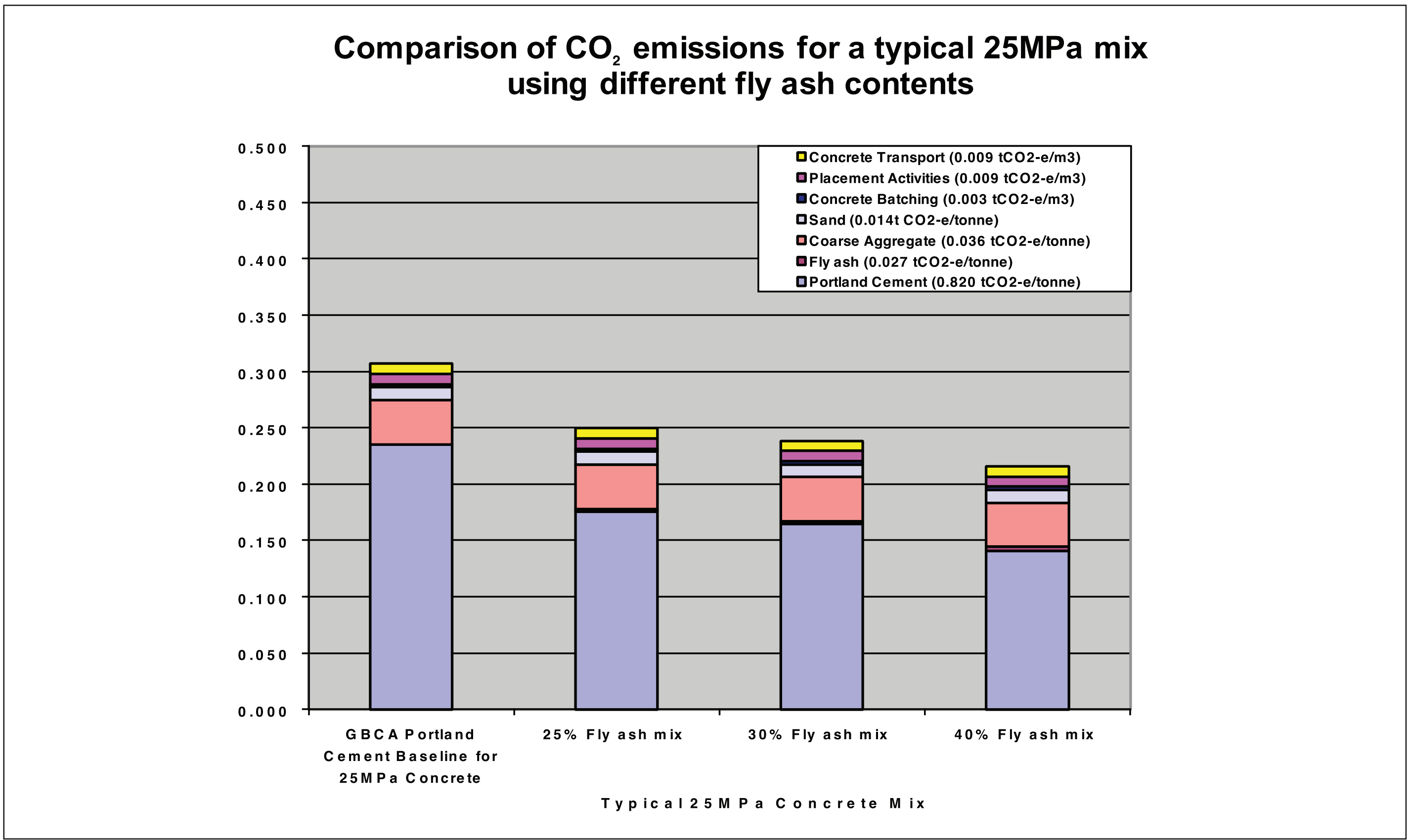

Figure 1 - Comparison of CO_2 Emissions for Typical 25 MPa Concretes With Varying Fly Ash Content (following references 17, 20 and 21)

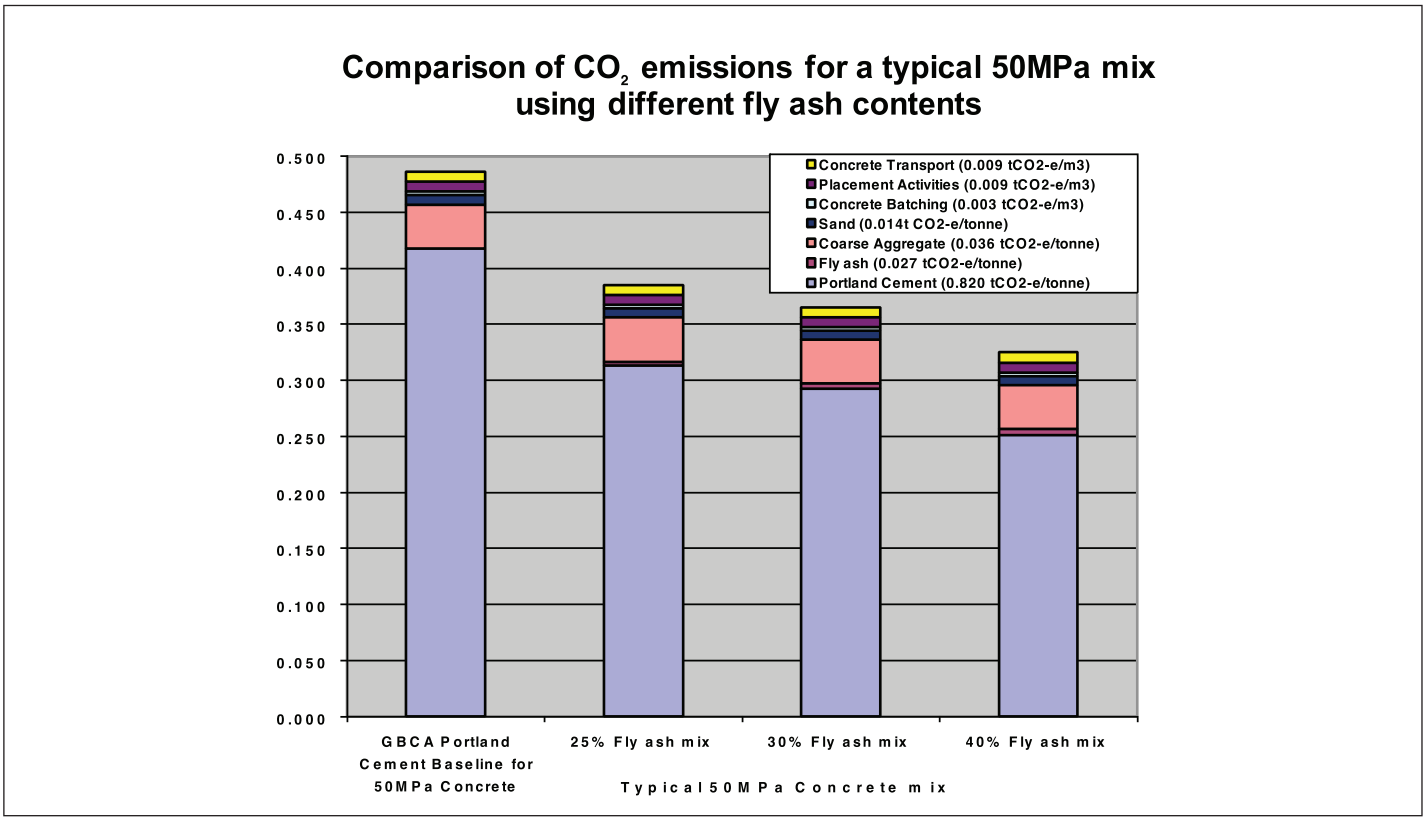

Figure 2 - Comparison of CO_2 Emissions for Typical 50 MPa Concretes With Varying Fly Ash Content (following references 17, 20 and 21)

By-Product Recovery and Reuse

In 2010, Australian coal fired power industry produced in excess of 14 million tonnes of coal combustion products, which includes fly ash, of which almost 1.9 million tonnes, or 14%, was used in concrete product manufacture[24]. Fly ash has great technical merit and is a valuable material with enormous potential for increased use in concrete. The reuse of fly ash and its diversion from long term storage ponds is highly economical as well as providing environmental and social benefits in line with the objective of concrete sustainability.

Reduction in Natural Resource Use

Cement production places a significant demand on our natural resources in terms of the processes involved in manufacture and inputs. It requires mining of natural raw materials including limestone, clay and shale and it also requires coal and gas for energy to drive the clinkering process. The use of fly ash as a partial cement replacement reduces the amount of cement required in concrete, thereby helping to preserve natural resources.

Durability and Service Life

The ability of fly ash to enhance the durability properties of concrete is well established[7]. More recently, the link between enhanced durability and sustainability has been explored[25]. Durable structures that are better designed to withstand chemical attack and physical stress have an increased service life and reduced need for maintenance. This maximises the return on the original capital as well as the natural resource use in the structure, translating into a higher level of sustainability measured over the life cycle of the concrete structure.

OPPORTUNITIES WITH THE USE OF FLY ASH IN SUSTAINABLE CONCRETE

The opportunities for using fly ash in the production of sustainable concrete are extensive and will continue to grow as concrete technology evolves, thus allowing the merits of fly ash to be commercially realised. With an understanding of the influences of fly ash on the early age and mechanical properties of concrete[7], it is possible to incorporate it in an appropriate proportion relevant to the design and construction requirements. Some applications and opportunities for fly ash are given below:

- Incorporation into Normal class concretes (defined in AS1379) where possible, to levels where minimum 7 day compressive strength requirements are achieved[26]. Typical proportions would be 15% to 25% for 20-32 MPa concrete and 25% to 35% for higher strength grades.
- Incorporation into Special class concretes[24] at a proportion where performance criteria can be achieved. This may vary from 15 to 30% for post-tensioned applications where early age criteria dominate, to values of 40% and over for applications where early strength is not required and acceptance age may be extended to 56 or 90 days.
- In the Green Star specification, achieving reductions in Portland cement contents in concrete relative to Reference Case levels in the concrete materials credit[4]. Specifically, reducing the Portland cement content by 30% to achieve 1 point or 40% cement reduction for 2 points.
- Up to 7.5% inclusion as a mineral addition in the manufacture of cement[27].
- As the main ingredient in alkali-activated cement, a technology based on using an alkaline solution to activate the polymerisation of fly ash (and/or slag) to produce an alternative binders and concretes, one example being geopolymer based material. Much research is being undertaken in this area[28] and while products are not yet in common use, it is one technology that provides solutions for the future.

CONCLUSIONS

Fly ash can be crucial to achieving sustainable concrete. Fly ash when used appropriately can; reduce costs, cement contents and associated embodied CO_2 emissions, placing less demand on the use of natural resources when used in concrete. Its inclusion in concrete can also increase structure sevice life and reduce maintance of concrete structures. These attributes are acknowledged by the GBCA using the Green Star rating tool where fly ash becomes a key strategy to reduce Portland cement levels in concrete by a defined 30% for 1 point and 40% for 2 points under the concrete materials credit.

While there is already awareness as to the benefits that fly ash can provide in the quest for sustainable concrete, given the volumes of fly ash being produced and technological advances in the concrete industry, much potential remains to further exploit its advantages. The challenge to achieve a sustainable concrete future will however require a paradigm shift by designers and builders from an accelerated construction schedule approach to a focus on increasing durability, service life, embodied energy, through the conservation of our natural resources using by-products where appropriate.

REFERENCES

1. Plank, R, "Sustainability Issues for Reinforced Concrete Construction", Concrete 2007 Proceedings, Concrete Institute of Australia, 23rd Biennial Conference, ISBN 0 909375 78 X, 2007.
2. Anderson, J.E. and Silman, R, "The Role of the Structural Engineer in Green Building:, The Structural Engineer, Vol. 87, No. 3, February, 2009.
3. The Concrete Centre, "Sustainable Concrete", The Environmental, Social and Economic Sustainability Credentials of Concrete, Report Reference TCC/05/03, ISBN: 1-904818-43-9, Available from www.concretecentre.com, 2007.
4. Green Building Council of Australia, "Green Star Rating Tool", Available from www.gbca.org.au, 2011.
5. Baweja, D. and Nelson, P., "Supplementary Cementing Materials: Their Acceptance in Australian Specifications", Sixth CANMET/ACI International Conference on Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete, ACI SP 178-27, Bangkok, Thailand, June, 1998, pp. 475-492.
6. Concrete Institute of Australia, "Fly Ash and Its Use in Concrete", Current Practice Note No. 25, ISBN 0 909375 61 5, November 2003, 8p.
7. Ash Development Association of Australia (ADAA), "Australian Experience with Fly Ash in Concrete: Applications and Opportunities", Fly Ash Technical Note No. 8, , Available from http://www.adaa.asn.au/technicalnotes.htm, November, 2009, 4p.
8. Standards Australia, Australian Standard AS3582.1, "Supplementary Cementitious Materials for Use With Portland and Blended Cement – Part 1: Fly Ash", ISBN 0 7337 1688 1, Standards Australia International, 1998.
9. Standards Australia, Australian Standard AS3972, "General Purpose and Blended Cements", ISBN 978 0 7337 9698 2, Standards Australia International, 2010.
10. Malhoutra, V.M., "Making Concrete Greener with Fly Ash", Concrete International, Vol. 21, No.5, May 1999.
11. Malhoutra, V.M., "Making Concrete Greener with Fly Ash", Concrete International, Vol. 21, No.5, May 1999.
12. Cement ,Concrete and Aggregates Australia, "Sustainable Concrete Buildings", Concrete – The Responsible Choice, Briefing, ISSN 1447-199X, Available from www.ccaa.com.au, April, 2010.
13. Cement ,Concrete and Aggregates Australia, "Sustainable Concrete Materials", Concrete – The Responsible Choice, Briefing, ISSN 1447-199X, Available from www.ccaa.com.au, April, 2010.
14. Mehta, P.K., "Global Concrete Industry Sustainability: Tools for Moving Forward to Cut Carbon Emissions", American Concrete Institute, Concrete Instenational, February, 2009, pp 45-48.
15. Wilson, J.L. and Tagaza, E., "Green buildings in Australia: Drivers and Barriers", Australian Journal of Structural Engineering, Vol. 7, No. 1, Engineers Australia, R.E. Melchers Editor,2006, pp 57-63.
16. Wilson, J.L. and Tagaza, E., "Green buildings in Australia: Drivers and Barriers", Australian Journal of Structural Engineering, Vol. 7, No. 1, Engineers Australia, R.E. Melchers Editor,2006, pp 57-63.
17. Heidrich, C., I. Hinczak, et al. (2005). Case study: CCP's potential to lower Greenhouse Gas emissions for Australia. World of Coal Ash 2005, Lexington, Kentucky, USA, American Coal Ash Association & University of Kentucky.
18. Flower, D., Sanjayan, J. and Baweja, D., "Environmental Impacts of Concrete Production and Construction", Proceedings, Concrete Institute of Australia Biennial Conference, Melbourne, Australia, 2005.
19. Flower, D., Sanjayan, J. and Baweja, D., "Environmental Impacts of Concrete Production and Construction", Proceedings, Concrete Institute of Australia Biennial Conference, Melbourne, Australia, 2005.
20. Heidrich, C., Hinczak, I., and Ryan, B. "SCM's potential to lower Australia's greenhouse gas emissions profile." Iron and Steel Slag Products: A Significant Time of Scarcity, Australasian Slag Association Conference, March 2005 (papers published on CD), Sydney.
21. Jenkins, D., Baweja, D. and Portella, J., "Optimising Building Design for Sustainability Using High Performance Concrete", Proceedings, Concrete 2011, Concrete Institute of Australia Biennial Conference, Building a Sustainable Future, Perth, Australia, October, 2011.
22. Jenkins, D., Portella, J. and Baweja, D., "Optimising Precast Bridge Girders for Sustainability with the use of High Performance Concrete", AUSTROADS 8th Bridge Conference, Proceedings, Vol. 4, ISBN 978 1 921709 81 4, V. Ponnampalam, E Ancich and H Madrio Editors, Sydney, Australia, November, 2011, pp 124-134.
23. Ash Development Association of Australia (ADAA), "Post-Tensioned Structural Fly Ash Concrete", Fly Ash Reference Data Sheet No. 9, Available from http://www.adaa.asn.au/documents/Ref_Data_Sheet_9.pdf, April, 2009, 5p.
24. Ash Development Association of Australia, ADAA Annual Membership Survey Results www.adaa.com.au January – December 2010.
25. Mehta, P.K., "Durability – Critical Issues for the Future", Concrete International, Vol. 19, No. 7, July 1997, pp 27-33.
26. Standards Australia, Australian Standard AS1379, "Specification and Supply of Concrete", ISBN 0 7337 1468 4, Standards Australia International, 2007.
27. Standards Australia, Australian Standard AS3972, "General Purpose and Blended Cements", ISBN 978 0 7337 9698 2, Standards Australia International, 2010.
28. Concrete Institute of Australia, "Geopolymer Concrete", Recommended Practice Z16, ISBN 1 921093 56 0, September, 2011, 38p.

ASH DEVELOPMENT ASSOCIATION OF AUSTRALIA (ADAA)

PO Box 1194 Wollongong NSW 2500 Australia
Telephone: +612 4228 1389 / Fax: +612 4258 0169
Email: adaa@adaa.asn.au / Web: www.adaa.asn.au