23rd Australasian Conference on the Mechanics of Structures and Materials

2014

The compressive strength of mortar made with cement containing limestone mineral addition, cement kiln dust and fly ash

B T. Benn
University of South Australia

D Baweja
University of Technology, Sydney

J E. Mills
University of South Australia

Publication details

Benn, BT, Baweja, D & Mills, JE 2014, 'The compressive strength of mortar made with cement containing limestone mineral addition, cement kiln dust and fly ash', in ST Smith (ed.), *23rd Australasian Conference on the Mechanics of Structures and Materials (ACMSM23)*, vol. I, Byron Bay, NSW, 9-12 December, Southern Cross University, Lismore, NSW, pp. 119-124. ISBN: 9780994152008.

23rd Australasian Conference on the Mechanics of Structures and Materials (ACMSM23)
Byron Bay, Australia, 9-12 December 2014, S.T. Smith (Ed.)

THE COMPRESSIVE STRENGTH OF MORTAR MADE WITH CEMENT CONTAINING LIMESTONE MINERAL ADDITION, CEMENT KILN DUST AND FLY ASH

B.T. Benn*
School of Natural and Built Environments, University of South Australia,
Adelaide, Australia. tom.benn@unisa.edu.au (Corresponding Author)

D. Baweja
School of Civil and Environmental Engineering, University of Technology Sydney,
Sydney, Australia. daksh.baweja@uts.edu.au

J.E. Mills
School of Natural and Built Environments, University of South Australia,
Adelaide, Australia. julie.mills@unisa.edu.au

ABSTRACT

This paper presents the findings, related to the effect of limestone mineral addition, cement kiln dust, fly ash and combinations of these materials, on the 28-day compressive strength of mortar specimens tested during the initial phase of a comprehensive research program. The main thrust of the research is to determine what effect increased levels of limestone mineral addition, when used in conjunction with cement kiln dust, will have on the chloride ion ingress of mortar/concrete. The mortars were manufactured to a constant water/binder ratio and cured under water until crushed. The results indicated that intergrinding the limestone is more effective than post blending the limestone, due to finer grinding and formation of nucleation points. The addition of up to 5% cement kiln dust did not adversely affect the compressive strength of cement only mixes. In mixes made with 20% and 30% fly ash replacement of cement, the use of limestone mineral addition and/or cement kiln dust appeared to improve the activation of the fly ash, as compressive strengths were all greater than the control mix at 28-days, with the total binder level and water/binder ratio being equal in all mixes. The compressive strength results of this phase have indicated that the use of increased levels of limestone mineral addition in cement will not be detrimental to the strength development of mortar or concrete.

KEYWORDS

Limestone mineral addition, cement kiln dust, fly ash, Type GP cement, compressive strength.

INTRODUCTION

This paper will present the findings, related to the effect of limestone mineral addition (LMA), cement kiln dust (CKD), fly ash (FA) and combinations of these materials on the 28-day compressive strength of mortar specimens tested as part of a comprehensive research program. The research program is currently being undertaken at the University of South Australia (UniSA), to investigate the effect that increased levels of LMA, when used in conjunction with CKD, will have on the chloride ion ingress of mortar/concrete.

The research was prompted by the 2010 revision of the Australian cement standard AS 3972 Portland and blended cement (1997). This revision, following an extensive testing program that commenced in 2008 and which was based around LMA, resulted in the changes listed:

- The name of the standard was changed to AS 3972 – General purpose and blended cement.
- The maximum mineral addition level was increased from 5% to 7.5%.
- Up to a maximum of 5% of the 7.5% mineral addition could be cement kiln dust.
- A maximum chloride level of 0.10% in all cement was introduced.
- A new cement type; "General Limestone Cement", Type GL, with a limestone content of between 7.6% and 20% was incorporated.

EXPERIMENTAL PROGRAM

Background

In various parts of Australia the Type GP cement containing LMA up to 7.5% has now been used for two years without any reported issues. This cement is equivalent to the European CEM I (EN 197-1 2000), the Canadian Type GU (CAN/CAS A3001 2008) and the American Type 1 (ASTM C150 2005 and ASTM C595/C595M 2012). In Australia Type GL cement, containing LMA greater than 7.5% has not been commercially manufactured to date, due to manufacturing and storage constraints.

The mix details for the 27 mixes made during this phase are summarised in Table 1, where 'binder' implies the cementitious material that is cement and mineral addition (including the CKD) or cement, mineral addition and fly ash. Cement only mixes were compared to mixes in which the cement was replaced by 20% and 30% fine fly ash.

Table 1. Mix details (Benn B.T., Baweja D. and Mills J.E. 2014)

Mix	Nominal limestone content	CKD content	Sand/binder ratio	Water/binder ratio
Cement only	4%	Zero, 2%, 5%	1.99	0.40
	10%	Zero, 2%, 5%	1.99	0.40
	15%	Zero, 2%, 5%	1.99	0.40
Cement with 20% FA	4%	Zero, 2%, 5%	1.93	0.40
	10%	Zero, 2%, 5%	1.93	0.40
	15%	Zero, 2%, 5%	1.93	0.40
Cement with 30% FA	4%	Zero, 2%, 5%	1.89	0.40
	10%	Zero, 2%, 5%	1.89	0.40
	15%	Zero, 2%, 5%	1.89	0.40

Adelaide Brighton Cement Ltd supplied the Type GP containing 4% limestone and trial cement interground with 10% limestone, fine fly ash from the Port Augusta power station and CKD typical of the material extracted from the kiln at their Birkenhead plant. The cement containing 15% LMA was a blend of cement with 10% interground limestone plus an additional 5% fine ground limestone.

Mix Details

The mix proportions for the mixes are detailed in Tables 2-4, the mix code, M04.0.00, implies the following; M means mortar; 04, 10 or 15 indicates the percentage limestone level; zero, 2 or 5 indicates the CKD level and 00, 20 or 30 indicates the level of fly ash replacement.

Notes on materials detailed in the Tables below:
1. Limestone interground during milling at 4% and 10% respectively.
2. Additional 5% fine ground limestone added to cement containing 10% interground limestone to produce a 15% LMA level.
3. CKD at 2 or 5% is percentage of LMA (e.g. 2% of 4% in Mix M2 equals 0.02 x 26.8 kg = 0.536 g).
4. FA is given as percentage of total cementitious material (i.e. 20% or 30% of 670 kg).

5. The quantity of sand was adjusted when fly ash was used to ensure that the mixes yielded one cubic metre.

Table 2. Mix proportions cement only mixes

Mix Code	M 04.0.00	M 10.0.00	M 15.0.00	M 04.2.00	M 10.2.00	M 15.2.00	M 04.5.00	M 10.5.00	M 15.5.00
Mix No.	M1	M8	M20	M2	M9	M21	M3	M10	M22
	kg/m^3	kg/m^3	kg/m^3	kg/m^3	kg/m^3	kg/m^3	kg/m^3	kg/m^3	kg/m^3
Cement binder	670 [1]	670 [1]	670 [2]	670 [1,3]	670 [1,3]	670 [2,3]	670 [1,3]	670 [1,3]	670 [2,3]
Fly ash [4]	0	0	0	0	0	0	0	0	0
Sand [5]	1332	1332	1332	1332	1332	1332	1332	1332	1332
Water	270	270	270	270	270	270	270	270	270

Table 3. Mix proportions for mixes with 20% fly ash replacement of cement

Mix Code	M 04.0.20	M 10.0.20	M 15.0.20	M 04.2.20	M 10.2.20	M 15.2.20	M 04.5.20	M 10.5.20	M 15.5.20
Mix No.	M5	M11A	M23	M6	M12	M24	M7	M13	M25
	kg/m^3	kg/m^3	kg/m^3	kg/m^3	kg/m^3	kg/m^3	kg/m^3	kg/m^3	kg/m^3
Cement binder	536 [1]	536 [1]	536 [2]	536 [1,3]	536 [1,3]	536 [2,3]	536 [1,3]	536 [1,3]	536 [2,3]
Fly ash[4]	134	134	134	134	134	134	134	134	134
Sand [5]	1295	1295	1290	1295	1295	1290	1295	1295	1290
Water	270	270	270	270	270	270	270	270	270

Table 4. Mix proportions for mixes with 30% fly ash replacement of cement

Mix Code	M 04.0.30	M 10.0.30	M 15.0.30	M 04.2.30	M 10.2.30	M 15.2.30	M 04.5.30	M 10.5.30	M 15.5.30
Mix No.	M14	M17	M26	M15	M18	M27	M16	M19	M28
	kg/m^3	kg/m^3	kg/m^3	kg/m^3	kg/m^3	kg/m^3	kg/m^3	kg/m^3	kg/m^3
Cement binder	469 [1]	469 [1]	469 [2]	469 [1,3]	469 [1,3]	469 [2,3]	469 [1,3]	469 [1,3]	469 [2,3]
Fly ash[4]	201	201	201	201	201	201	201	201	201
Sand [5]	1273	1273	1269	1273	1273	1269	1273	1273	1269
Water	270	270	270	270	270	270	270	270	270

Specimens

The cylinder specimens were compacted in three layers with 25 tamps per layer using a compacting hammer, as the mortar was too "soft" to compact with the slump rod. The specimens were demoulded after 24 hours and cured in water at 23 ± 2 °C in accordance with AS 1012.8.1 (2000). The specimens were weighed and dimensions measured before being crushed on an Avery 1,800 kN compressive testing machine in accordance with AS 1012.9 (1999)

RESULTS AND DISCUSSION

The results shown in Tables 5 and 6 include the 28-day compressive strengths, the cylinder densities, and percentage change in strength compared to the control mix. Due to the limited number of cylinders crushed at 28 days a statistical analysis of the differences between mixes was not possible, thus the author has adopted the following parameters to explain any differences. A percentage change, from the control, of less than 4% indicated no difference (ND) as this could be attributed to laboratory test variation, based on information from testing laboratories that indicates that this is between 1–2 MPa. A change of greater than 4% but less than 10% indicated a minor difference (MD), whereas a difference of greater than 10% indicated a significant difference (SD) as this is essentially equivalent to a change in mix strength grade at above 40 MPa, which was achieved in all mixes.

Figure 1 indicates that as the LMA increased the density of the concrete tended to decrease, except when the FA replacement was at 30%, which was more variable. The average density of the concrete was similar for a given binder type but decreased as the percentage FA increased (cement only mixes = 2216 kg/m^3, 20% FA mixes = 2186 kg/m^{3}and 30% FA mixes = 2179 kg/m^3).

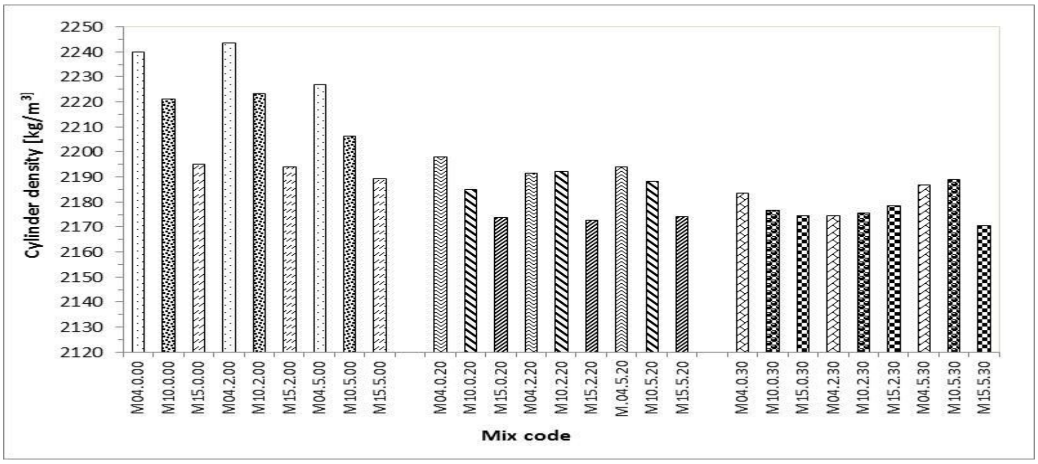

Figure 1. Density of 28-day cylinders

Table 5 and Figure 2 show that for up to 10% interground LMA there was no significant decrease in the 28-day compressive strengths but with 15% LMA level, where an additional 5% fine limestone was post blended with the 10% interground cement, there was a significant reduction in strength. This is probably due to the added limestone not being as fine as interground limestone because when interground, the limestone tends to grind more easily (Tsivilis et al. 2002) and form nucleation points (Bonavetti et al. 2003).

Table 5. Effect of LMA & CKD on results of cement only mixes

Effect of limestone mineral addition					Effect of cement kiln dust addition				
Mix Code	Mix No.	28-day (MPa)	% change	Difference	Mix Code	Mix No.	28-day (MPa)	% change	Difference
M04.0.00	1	55.4	control	-	M04.0.00	1	55.4	control	-
M10.0.00	8	55.5	0	ND	M04.2.00	2	53.4	-3.6	ND
M15.0.00	20	46.1	-16.8	SD	M04.5.00	3	50.2	-9.4	MD
M04.2.00	2	53.4	control	-	M10.0.00	8	55.4	control	-
M10.2.00	9	53.0	-0.7	ND	M10.2.00	9	53.0	-4.3	MD
M15.2.00	21	45.9	-14.0	SD	M10.5.00	10	56.5	+2.0	ND
M04.5.00	3	50.2	control	-	M15.0.00	20	46.1	control	-
M10.5.00	10	56.5	+12.6	SD	M15.2.00	21	45.9	-0.4	ND
M15.5.00	22	51.0	+1.6	ND	M15.5.00	22	51.0	+10.6	SD

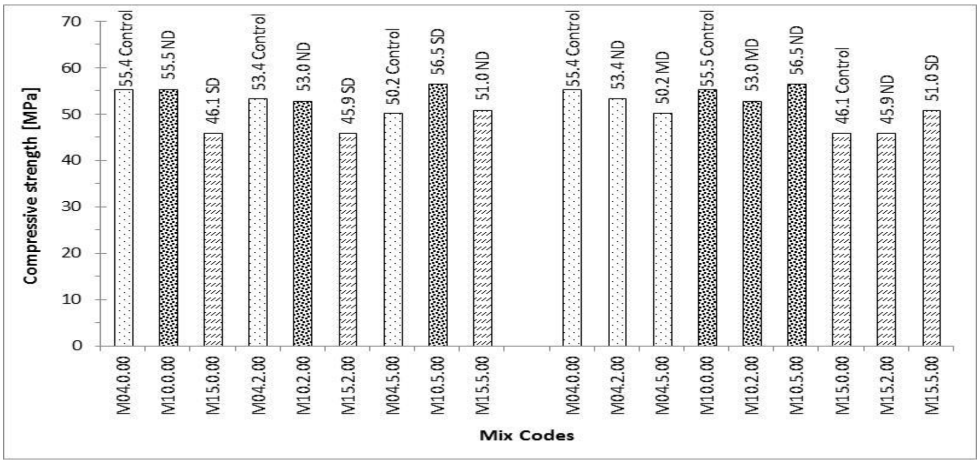

Figure 2. Influence of LMA and CKD on 28-day compressive strengths in cement only mixes

Figure 2 also shows that for a given LMA level there was no difference or only a minor difference in strength with either 2% or 5% CKD, however with 15% LMA cement plus 5% CKD there was significant increase in strength. The latter result needs to be investigated further.

Table 6. Cement only mixes compared to mixes with 20% and 30% fly ash replacement of cement

Mix Code	Mix No.	Density kg/m^3	28-day (MPa)	% change	Comments on differences
M04.0.00	1	2240	55.5	control	
M04.0.20	5	2198	60.2	+8.7	Minor difference, later age hydration of FA
M04.0.30	14	2184	59.4	+7.2	Minor difference, later age hydration of FA
M04.2.00	2	2244	53.4	control	
M04.2.20	6	2192	67.8	+27.0	Significant difference, FA hydration influenced by CKD
M04.2.30	15	2175	68.2	+27.7	Significant difference, FA hydration influenced by CKD
M04.5.00	3	2227	50.2	control	
M04.5.20	7	2194	66.6	+32.7	Significant difference, FA hydration influenced by CKD
M04.5.30	16	2187	64.4	+28.3	Significant difference, FA hydration influenced by CKD
M10.0.00	8	2222	55.5	control	
M10.0.20	11A	2185	61.6	+11.2	Significant difference, FA hydration influence by LMA
M10.0.30	17	2177	64.1	+15.7	Significant difference, FA hydration influence by LMA
M10.2.00	9	2223	53.0	control	
M10.2.20	12	2192	61.5	+16.0	Significant difference, FA hydration influence by CKD & LMA
M10.2.30	18	2176	61.2	+15.5	Significant difference, FA hydration influence by CKD & LMA
M10.5.00	10	2207	56.5	control	
M10.5.20	13	2189	58.0	+3.6	No difference
M10.5.30	19	2189	61.6	+10.0	Significant difference, FA hydration influence by CKD & LMA
M15.0.00	20	2195	46.1	control	
M15.0.20	23	2174	60.9	+32.1	Significant difference, FA hydration influence by LMA
M15.0.30	26	2175	53.5	+16.1	Significant difference, FA hydration influence by LMA
M15.2.00	21	2194	45.9	control	
M15.2.20	24	2173	50.9	+10.9	Significant difference, FA hydration influence by CKD & LMA
M15.2.30	27	2179	51.8	+12.9	Significant difference, FA hydration influence by CKD & LMA
M15.5.00	22	2195	51.0	control	
M15.5.20	25	2175	58.4	+14.5	Significant difference, FA hydration influence by CKD & LMA
M15.5.30	28	2171	51.2	+0.4	No difference

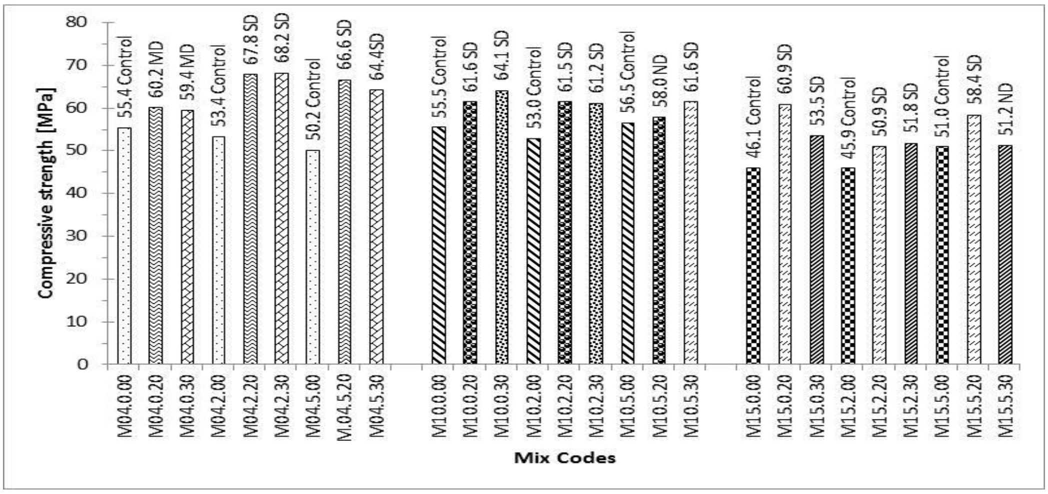

Figure 3. Chart of LMA and CKD effect on FA replacement mixes

The results shown in Table 6 and Figure 3 indicate that the use of FA as a cement replacement increased the 28-day compressive strengths irrespective of the level of LMA. This is probably due to the formation of nucleation points created by the limestone (Bonavetti et al. 2003) that activate the FA.

CONCLUSIONS

The results of this initial phase of the research indicate that:

- There was no detrimental change in the 28-day compressive strengths in mixes with up to 10% interground LMA in cement only mixes.
- The addition of 2% or 5% CKD to the cement did not significantly decrease the 28-day compressive strengths in cement only mixes.
- In mixes made with a cement containing a blend of 10% interground LMA and 5% added fine limestone there was a reduction in the 28-day compressive strengths compared to mixes made with up to 10% interground limestone.
- There was an increase in the 28-day compressive strengths in mixes where the LMA and CKD levels were the same but where the cement was replaced by either 20% or 30% fly ash.

ACKNOWLEDGMENTS

The authors acknowledge Adelaide Brighton Cement Ltd for their ongoing support and the 2013 final year civil engineering students of UniSA for their help with mixing and testing of specimens.

REFERENCES

American Society for Testing and Materials (2005) *ASTM C150 - Standard Specification for Portland cement*, ASTM International, West Conshohocken, PA.

American Society for Testing and Materials (2012) *ASTM C595/C595M - Standard Specification for Blended Hydraulic Cements,* ASTM International, West Conshohocken, PA.

Benn, B.T., Baweja, D. and Mills, J.E. (2014) "The influence of increased levels of limestone mineral addition used in combination with cement kiln dust on chloride ion penetration", *Proceedings of the RILEM International workshop on Performance-based specification and control of concrete durability*, Zagreb, Crotia, 11-13 June 2014, pp 167-174.

Bonavetti, V., Donza, H., Menéndez, G., Cabrera, O. & Irassar, E.F. (2003) "Limestone Filler in Low w/c Concrete: A Rational Use of Energy", *Cement and Concrete Research*, vol. 33, no. 6, pp 865-871.

Canadian Standards Association (1983) *CAN/CSA-A5-'Portland cement'*, CSA, Mississauga, Ontario, Canada.

Canadian Standards Association (2008) *CAN/CSA A3001-2008 - Cementitious Materials for Use in Concrete*, CSA, Mississauga, Ontario, Canada.

European Committee for Standardization (1992) *EN 197-1-1992 - Cement–composition, specification and conformity criteria: Common cements,* Brussels, Belgium.

European Committee for Standardization (2000) *EN 197-1-2000 - Cement–composition, specification and conformity criteria: Common cements,* Brussels, Belgium.

Standards Association of Australia (1997) *Portland and blended cements*, (AS 3972), Standards Australia, Sydney.

Standards Association of Australia, (2000) *Methods of testing concrete, Method of making and curing concrete – Compression and indirect tensile test specimens, (AS 1012.8.1),* Standards Australia, Sydney.

Standards Association of Australia, (2000) *Methods of testing concrete, Determination of the compressive strength of concrete specimens, (AS 1012.9),* Standards Australia, Sydney.

Standards Association of Australia (2010) *General purpose and blended cements*, (AS 3972), Standards Australia, Sydney.

Tsivilis, S., Chaniotakis, E., Kakli, G., & Batis, G. (2002), "An analysis of the properties of portland limestone cements and concrete", *Cement and Concrete Composites,* vol. 24, pp 371-378.