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On the mechanism of strength enhancement of cement paste and mortar with triisopropanolamine

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Abstract

Recent work on the strength-enhancing mechanism of triisopropanolamine (TIPA) suggested that TIPA enhances the mechanical properties of mortar and concrete by acting on the interfacial transition zone (ITZ) between paste and sand or aggregate rather than improving the properties of the hydrated binder. This paper presents compressive strength data for 10 Portland cements tested as cement paste as well as two different kinds of mortar after 28 days hydration, so that these two mechanisms could be compared directly. The average strength improvement with TIPA was 10% in the hydrated portland cement paste and 9% in the mortar, clearly showing that the strength enhancement is not dependent on an ITZ mechanism.

Keywords: Compressive strength; Cement paste; Interfacial transition zone; Admixture

1. Introduction

Perez et al. [1] recently proposed that triisopropanolamine (TIPA) does not improve the mechanical properties of hydrated portland cement paste, but rather improves mortar and concrete strength by acting on the interfacial transition zone (ITZ) between the portland cement paste and sand or aggregate. Perez et al. based their conclusion on studies of a model portland cement that did not display any increase in the degree of hydration or compressive strength in the presence of TIPA, but displayed significant strength enhancement of mortar made with the model portland cement and limestone. Previously, Gartner and Myers [2] and Chiesi et al. [3] presented ample data on the effect of TIPA on the degree of cement hydration and corresponding strength development in mortar, supporting the then proposed facilitated iron transport model. However, while demonstrating an overall increased degree of cement hydration in the presence of TIPA, this work did not specifically address the mechanical properties of the hydrated portland cement paste or any effect of TIPA on the ITZ between hydrated portland cement paste and sand or aggregate. Ichikawa et al. [4] presented evidence that TIPA, besides enhancing the hydration of ferrite and alite, also promotes the hydration of limestone, thereby indicating an effect of TIPA on the ITZ between portland cement paste and limestone fines in addition to the effect of TIPA on hydrated portland cement paste without limestone fines. However, again Ichikawa et al. [4] did not specifically address the effect of TIPA on the mechanical properties of hydrated portland cement paste.

This paper presents data on the compressive strength of hydrated portland cement paste (no ITZ between paste and sand) and mortar after 28 days hydration, thereby addressing the effect of TIPA on the mechanical properties of hydrated portland cement paste and, indirectly, the effect of TIPA on the transition zone between the paste and siliceous sand. TIPA is a proprietary alkanolamine used in the CBA series of strength-enhancing cement additives by W.R. Grace.

2. Experimental

In the first test series, six industrial portland cement clinkers representing a variety of chemical compositions were ground with gypsum in a laboratory mill to produce portland cement according to Table 1, cements 1A–1F.

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Table 1
Composition of laboratory prepared cements, Test Series 1 and 2

Cement ID	1A	1B	1C	1D	1E	1F	2G	2H	2I	2K
Chemical analysis, %										
SiO_2	21.71	20.96	19.93	20.19	21.32	19.55	20.86	22.07	21.14	20.48
Al_2O_3	4.35	5.15	4.42	5.32	4.71	5.55	4.00	3.30	5.01	3.63
Fe_2O_3	2.97	4.32	4.21	2.93	2.04	3.83	3.33	3.13	3.63	3.46
CaO	61.86	63.66	62.28	61.49	65.85	63.31	64.61	62.75	63.84	63.06
MgO	2.97	0.68	1.35	2.47	0.73	2.14	1.09	3.64	2.01	4.93
Cement SO_3	2.61	2.51	3.37	3.22	3.45	2.86	2.88	2.48	2.44	2.50
Clinker SO_3	0.45	0.35	1.25	1.09	1.34	0.72	N/A	N/A	N/A	N/A
Na_2O	0.06	0.11	0.2	0.17	0.12	0.06	0.18	0.29	0.24	0.16
K_2O	0.93	0.45	0.71	1.43	0.18	0.73	0.64	0.36	0.27	0.44
TiO_2	0.4	0.3	0.18	0.28	0.18	0.28	0.17	0.17	0.23	0.22
P_2O_5	0.15	0.12	0.18	0.08	0.41	0.06	0.05	0.12	0.17	0.06
Mn_2O_3	0.18	0.03	0.32	0.06	0.07	0.05	0.04	0.10	0.02	0.05
SrO	0.05	0.06	0.18	0.2	0.06	0.16	0.04	0.08	0.08	0.06
Na_2O equiv.	0.67	0.41	0.67	1.11	0.24	0.54	0.60	0.52	0.42	0.45
Loss on ignition	1.50	1.53	2.52	1.73	0.70	1.37	1.80	1.09	0.85	0.94
Calculated compounds										
C_3S	46	52	57	48	62	58	65	54	53	65
C_2S	28	21	14	22	15	12	11	23	20	10
C_3A	7	6	5	9	9	8	5	3	7	4
C_4AF	9	13	13	9	6	12	10	10	11	11
Physical analysis										
Blaine surface area (m^2/kg)	380	379	377	379	370	370	395	416	362	394

Each cement was tested for the 28-day compressive strength without additive and with 200 ppm TIPA added to the mix water, as cement paste and in mortar according to Table 2. A commercial planetary mixer was used to prepare the portland cement paste by mixing portland cement with deionised water at lowest speed mixing for 2 min. A w/c of 0.35 was chosen for all portland cement pastes in order to minimize any effect of bleeding. Nine 2.54-mm (1-in.) cubes of portland cement paste were prepared using plastic moulds, otherwise prepared, cured and tested according to EN 196 specifications [5]. The corresponding mortar tests in the first test series were carried out according to EN 196 specifications, using four specimens per data set. EN 196 mortar [5] is similar to ASTM C109 mortar [6] except that the w/c ratio, sand grading and cement content are different.

To further clarify the effect of the sand used and to verify the results obtained on laboratory ground cements, a second test series was carried out using four industrial portland cements representing a variety of chemical compositions

Table 2
Twenty-eight-day compressive strength data on hydrated portland cement paste and EN 196 mortar, Test Series 1

Cement ID	1A		1B		1C		1D		1E		1F	
	Paste	EN 196	Paste	EN 196	Paste	EN 196	Paste	EN 196	Paste	EN 196	Paste	EN 196
w/c	0.35	0.5	0.35	0.5	0.35	0.5	0.35	0.5	0.35	0.5	0.35	0.5
Blank (no admixture)												
28-Day MPa	85	48	108	60	86	55	62	42	119	67	88	49
S.D. MPa	2.0	1.4	7.8	1.1	3.0	1.5	5.5	0.2	7.4	3.2	3.2	2.3
CV, %	2.3	2.9	7.2	1.8	3.5	2.7	8.8	0.6	6.2	4.8	3.7	4.6
200 ppm TIPA (by weight of cement, added to mix water)												
28-Day MPa	94	54	122	62	104	60	65	44	121	66	97	58
S.D. MPa	5.7	2.1	4.6	1.4	5.7	2.2	5.5	0.9	9.2	2.0	2.9	1.1
CV, %	6.1	4.0	3.8	2.3	5.5	3.7	8.5	2.0	7.6	3.1	3.0	1.8
TIPA % of blank	111	113	113	103	121	109	105	105	102	99	110	118
TIPA effect on air, %	N/A	+0.9	N/A	+2.1	N/A	+2.4	N/A	+0.6	N/A	+1.40	N/A	+0.4
Average	*Paste*	*EN 196*										
TIPA % of blank	110	108										
TIPA effect on air content, %	N/A	+1.3										

Table 3
Twenty-eight-day compressive strength data on hydrated portland cement paste and micro mortar, Test Series 2

Cement ID	2G		2H		2I		2K	
	Paste	Micro mortar	Paste	Micro mortar	Paste	Micro mortar	Paste	Micro mortar
w/c	0.35	0.42	0.35	0.42	0.35	0.42	0.35	0.42
Blank (no admixture)								
28-Day MPa	110	92	92	81	88	80	92	82
S.D. MPa	4.6	2.3	4.9	3.7	6.3	2.7	5.1	2.6
CV, %	4.2	2.5	5.3	4.6	7.1	3.4	5.5	3.2
200 ppm TIPA (by weight of cement, added to mix water)								
28-Day MPa	124	105	96	89	96	85	105	95
S.D. MPa	4.7	4.4	5.6	5.2	4.9	3.7	5.6	5.9
CV, %	3.8	4.2	5.8	5.9	5.2	4.4	5.3	6.2
TIPA % of blank	113	114	104	110	109	106	114	116
TIPA effect on air, %	0	+0.1	+0.4	0	+0.2	+0.6	−0.4	−0.2
Average	*Paste*	*Micro mortar*						
TIPA % of blank	110	112						
TIPA effect on air content, %	0	+0.1						

according to Table 1, cement 2G–2K. The portland cement pastes were prepared and tested as in the first test series. However, a micromortar with a different type and amount of quartz sand was designed for the second test series in order to verify the results from the first test series on a different type of mortar. The micromortar in the second test series was therefore prepared by mixing one part of portland cement with one part of a pure quartz sand with 90% passing #70 sieve (0.212-mm mesh) at w/c 0.42; otherwise the micromortar was prepared according to EN 196 specifications [5]. The micromortar was cast, cured and tested in the same way as described for the portland cement paste. A relative air content was calculated by unit weight measurements for the mortar in the first and second test series as well as for the paste in the second test series. No unit weight measurements were done for the paste in the first test series, as not enough material was available. However, the very limited air entrainment for the paste in the second test series indicates that TIPA would not be expected to have any significant effect on the air content in cement paste.

3. Results

The measured compressive strength data after 28 days hydration for portland cement paste and mortar without admixture and with 200 ppm TIPA by weight of cement is shown in Table 2 for the first test series and in Table 3 for the second test series. The relative air content is also given when available.

A t test for unpaired data with unequal variance was performed comparing the compressive strength gain in portland cement paste and mortar. The t probability was .58, indicating that there was no statistically significant difference between the strength gain in portland cement paste and mortar. The t probability (also known as P) determines if there is a statistically significant difference between the two means. If this value is below a certain level (usually .05), the conclusion is that there is a difference between the two group means.

4. Discussion

The average strength improvement with TIPA was 10% in the hydrated portland cement paste in both test series, as compared to 8% and 12% in the two mortar test series, respectively. The average strength improvement with TIPA was 9% when combining the two mortar test series. The results clearly show that the strength enhancement is not dependent on an ITZ mechanism. The average strength improvement with TIPA was higher than the pooled standard deviation for both hydrated cement paste and mortar, indicating its statistical significance. However, the average effect of TIPA on the air content of paste and mortar was zero and +0.8%, respectively. If one assume that a 1% increase in the relative air content corresponds to a 4% loss of compressive strength in mortar, then the average air corrected strength improvement in mortar with TIPA was 12% or slightly higher than the average strength improvement in hydrated cement paste. The results therefore indicate that the "ITZ-strengthening" effect of TIPA proposed by Perez et al. [1] is not a major mechanism of strength enhancement of portland cement mortar made with siliceous sand, although it cannot altogether be ruled out as a minor contribution to mortar strength. On the other hand, it is well known that TIPA also promotes the hydration of limestone fines [4], thereby indicating an effect of TIPA on the ITZ between portland cement paste and limestone fines in addition to the here demonstrated effect of TIPA on hydrated portland cement paste without limestone. Perez et al. [1] used limestone aggregates in their work that might explain why they observed strength gain in mortar but not in paste. However, the conclusion based on testing of a single cement by Perez et al. [1] that TIPA has no effect on the mechanical properties of pure cement paste appears not valid.

5. Conclusion

The 28-day compressive strength testing of parallel samples of hydrated portland cement paste and mortar using 10 different portland cements resulted in significant strength gains in both paste and mortar treated with TIPA. The average strength improvement with TIPA was 10% in the hydrated portland cement paste and 9% in the mortar. The improvements are identical within the limits of testing error. The results clearly show that the strength enhancement is not dependent on an ITZ mechanism. The observed strength gain in hydrated portland cement paste confirms that TIPA is able to enhance the mechanical properties of hydrated portland cement paste without any paste–aggregate ITZ being present, thus supporting the model presented by Gartner, Myers and Chiesi [2,3].

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