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Compressive Strength of Medium Strength M30 Grade Self Compacting Concrete Using Waterbased Curing Techniques

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Abstract: Self-Compacting Concrete (SCC) is highly workable concrete with high strength and high performance that can flow under its own weight through restricted sections without segregation and bleeding. SCC is achieved by reducing the volume ratio of aggregate to cementitious materials, increasing the paste volume and using various viscosity enhancing admixtures and superplasticizers. It is observed that the behaviour of the design concrete mix is significantly affected by variation in humidity and temperature both in fresh and hardened state. In this study, effect of 5 water-based curing techniques on compressive strength of M30 grade Self-Compacting Concrete (SCC) is discussed. It is observed that immersion method for curing gives maximum compressive strength while the lowest compressive strength is for ice curing. Hot water and sea water give 2nd highest strength at 28 days. It is concluded that, although pond immersion method is best for curing in extreme weather conditions SCC can prove effective for hot weather and sea water conditions. Wet covering method is quite effective giving about 92% strength than that of strength received from immersion method. In cold weather compressive strength gain is quite less about 82%.

Key words: Self compacting concrete, immersion curing, hot water curing, ice curing, sea water curing, grade, wet covering, curing period, compressive strength

INTRODUCTION

Self-Compacting Concrete (SCC) is highly workable concrete with high strength and high performance that can flow under its own weight through restricted sections without segregation and bleeding (EFNARC, 2002). SCC has substantial commercial benefits because of ease of placement in complex forms with congested reinforcement (Khayat *et al*., 1999).

As per Vijai *et al*. (2010), SCC is achieved by reducing the volume ratio of aggregate to cementitious materials, increasing the paste volume and using various viscosity enhancing admixtures and superplasticizers. It is the use of superplasticizer which has made it possible to use w/c ratio as low as 0.25 or even lower and yet to make flowing concrete to obtain strength of the order 120 MPa or more. Building elements made of high strength concrete are usually densely reinforced.

Kumbhar *et al*. (2011), observed that the behaviour of the design concrete mix is significantly affected by variation in humidity and temperature both in fresh and hardened state. The strength of concrete is affected by a number of factors, one of which is the length of time for which it is kept moist, i.e., cured another being the method of curing. Inadequate or insufficient curing is one of main factors contributing to weak powdery surfaces with low abrasion resistance and durability.

Exposed surfaces of concrete shall be kept continuously in a damp or wet condition by ponding or by covering with a layer of sacking, canvas, hessian or similar materials and kept constantly wet for at least 7 days from the date of placing concrete in case of ordinary portland cement and at least 10 days where mineral admixtures or blended cements are used. IS 456 (2000) Cement Concrete and Aggregates Australia (CCAA, 2006) in a data sheet mention that curing is the process of controlling the rate and extent of moisture loss from concrete during cement hydration. This can be achieved by:

- Either supplying the water from outside (ponding and spraying)
- Continuously wetting the exposed surface thereby preventing the loss of moisture from it
- Leaving formwork in place
- Covering the concrete with an impermeable member
- Application of a suitable chemical (wax, etc.)
- Mixing a suitable chemical in fresh concrete for internal curing
- Combination of such methods

Qureshi *et al*. (2010), experimented on high strength self compacting concrete by curing with 3 different

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techniques. First in a temperature controlled curing tank in the laboratory, 2nd under prevailing site conditions and 3rd by application of a curing compound. They noted that 28 days compressive strength of cylinders cured under site conditions was 89% of the compressive strength of cylinders cured in water tank in the laboratory (i.e., 11% less). Similarly, compressive strength of cylinders cured by applying curing compound was 93% of the compressive strength of cylinders cured in the laboratory (i.e., 7% less).

Stegmaier (2005), investigated the effect of heat treatment on the mechanical properties of SCC. Various SCCs were brought to a maturity corresponding to a durable storage of the concretes for 3 days at 20°C. On these concretes, the compressive strength, the splitting tensile strength and the static Young's modulus were determined and compared to reference concretes that had been stored for 3 days under standard conditions. The concretes with a low (w/c) ratio which are typically used in the precast industry are hardly affected by the heat treatment conditions. This applies independent from the curing temperature. A high (w/c) ratio leads in part to marked loss of strength which in most cases increases with increasing curing temperature. For the splitting tensile strength, heat curing temperatures up to 60°C can be regarded as uncritical. Beyond this temperature, strength losses compared to standard storage have to be reckoned with.

The strength of concrete is affected by a number of factors, one of which is the length of time for which it is kept moist, i.e., cured, another being the method by which it is being cured. Inadequate or insufficient curing is one of main factors contributing to weak, powdery surfaces with low abrasion resistance.

In the present study, researchers have chosen 5 different methods of curing in which water or ice is used as supplementary curing medium:

- Traditional immersion or pond method acronym M3I
- Hot water curing M3H
- Ice curing M3B
- Sea water curing M3S
- Gunny bag or wet covering M5W

The effect of these 5 water-based curing techniques on the compressive strength of M30 grade Self-Compacting Concrete (SCC) is discussed.

MATERIALS AND METHODS

The materials used in developing the reference M30 SCC have following properties:

Cement: Ordinary portland cement of 53 grade (Sanghi brand) with specific gravity 3.15, available in local market. The properties of cement used are given in Table 1.

Water: Water is an important ingredient of concrete, as it actually participates in the chemical reaction with cement. Potable water was used for mixing.

Sea water: The sea water was brought from gulf of Cambay having salinity 23%.

Fly ash: Class C fly ash was used with specific gravity 2.13, Vanakbori Thermal Station, Dist. Kheda, Gujarat, India. The properties of fly ash used are given in Table 2.

Aggregates (FA and CA): High strength or rich concrete can be adversely affected by use of large size aggregates as discussed in a text book of Concrete Technology (Shetty, 2005). Based on this fact and after studying mix design literature of SCC, the various aggregates used are as under: Sand = 4.75 mm: Specific gravity 2.55 and fineness modulus 2.87, Zone II, Bodeli, Vadodara. Grit, 4.75-12.5 mm: Specific gravity 2.75 and fineness modulus 5.76, Sevaliya, Kheda District. The properties of aggregates used are given in Table 3.

Table 1: Properties of cement

Properties	Values	IS CODE: 8112-1989 specifications
Specific gravity	3.15	3.10-3.15
Consistency	28%	30-35
Initial setting time	35 min	30 min Minimum
Final setting time	178 min	600 min Maximum
Compressive strength at 7 days N mm^{-2}	38.49 N mm^{-2}	43 N mm^{-2}
Compressive strength at 28 days N mm^{-2}	52.31 N mm^{-2}	53 N mm^{-2}

Table 2: Properties of fly ash

Constituents	Weight (%)
Loss on ignition	4.170
Silica (SiO_2)	69.400
Iron oxide (Fe_2O_3)	3.440
Alumina (Al_2O_3)	28.200
Calcium oxide (CaO)	2.230
Magnesium oxide (MgO)	1.450
Total sulphur (SO_3)	0.165
Insoluble residue	-
Sodium oxide (Na_2O)	0.580
Potassium oxide (K_2O)	1.260

Table 3: Properties of sand

Particulars	Sand	Grit
Source	Bodeli, Gujarat	Sevalia, Gujarat
Zone	Zone II	-
Specific gravity	2.55	2.75
Fineness modulus	2.87	5.76
Bulk density	1776 kg m^{-3}	1764 kg m^{-3}
Colour	Yellowish white	Greyish black

Superplasticizers (SP): Polycarboxylates ether Condensate (PCE) based superplasticizers were used Brand name Glenium B276 Suretec. Dosages of superplasticizers 1.1% of cementitious material. The properties of superplasticizer are: pH≥6, Chloride ion content <0.2% and light brown liquid in color.

Gunny bag: These are also called jute bags. They retain water and keep the samples wet. The bags were available from local market.

Mix proportion of SCC and preperation of specimen: There is no standard method for SCC mix design and many academic institutions, admixture suppliers, ready-mixed, pre cast and contracting companies have developed their own mix proportioning methods. Various trials were performed with 0.01 m^3 of concrete with locally available materials and checked the fresh property tests (Slump flow, J-ring flow, V-funnel, L-box and U-box) according to the standards of European guidelines and finalized the mix proportion of M30 grade of SCC, considered as a reference SCC. The selection of super plasticizer and its doses where fixed using marsh cone. Before finalizing the type of superplasticizer and its dosage, marsh cone method was used to study the effect of water/cement ratio and dosage of superplasticizer type on cement pastes with different superplasticizer dosages (Agullo *et al*., 1999).

Once the mix design was achieved, concrete cubes were cast. Slump flow test was carried out on each batch in order to ascertain concrete flow for self-compacting concrete. All concrete batches were prepared in rotating drum mixture. First, the aggregate are introduced and then one-half of the mixing water was added and rotated for approximate 2 min. Next, the cement and fly ash were introduced with superplasticizer already mixed in the remaining water. Most manufactures recommend at least 5 min mixing upon final introduction of admixture. The final mix design for reference mix adopted is shown in Table 4.

Tests conducted on fresh SCC: Various tests, such as slump flow and T50, J-Ring, L-Box, U-Box and V-funnel test were performed to study the workability of SCC. Test results and their acceptance criteria as per EFNARC are listed in Table 5.

Curing methods used: Three specimens were cured for each selected techniques of curing namely normal water immersion, hot water, ice, sea water and wet covering.

Water immersion: The specimens are placed in a water shallow pond immediately after de-moulding. They remain in pond continuously till the day of testing.

Hot water curing: In this test, the specimen are placed in airtight oven within 30 min of adding water. The oven is brought to temperature 93°C in an hour time and kept this temperature for 5 h. The specimen are removed from oven, stripped, cooled and tested within 30 min.

Ice curing: The specimens were placed in a ice making drum in an ice factory for the specified period. The temperature inside the drum is maintained at 0°C. The drums were taken out in the morning of the day of testing in order to thaw the ice before testing.

Sea water curing: The sea water was brought to laboratory from bay of Cambay and kept in small drums with specimens inside. This is quite similar to immersion curing.

Wet covering with gunny bags: Wet jute bag covers were placed, as soon as the specimens were de-molded to maintain water on the surface of the concrete. They were kept wet continuously for the entire period of experiments. The various acronyms used for specimens of tests are:

- M3I for pond immersion
- M3H for hot water curing
- M3S for sea water
- M3B for ice curing
- M3W for wet covering

Table 4: Mix proportions for reference mix design, material (m^{-3})

Reference mix	Cement (kg)	Fly-ash (kg)	Fine Aggt. (kg) Grit	Fine Aggt. (kg) Gravel	Coarse Aggt. (kg)	Water (L)	SP (%)
M30 SCC	375	175	785	0	735	214.5	1.07

Table 5: Fresh SCC properties of reference mix

Test method	Properties	Unit	Typical range of values as per EFNARC Min.	Typical range of values as per EFNARC Max.	Results of tests Mix. M30
Slump-flow	Filling ability	mm	600.0	800.0	620.00
T 50-slump flow	Filling ability	sec	2.0	5.0	3.80
L-Box	Passing and segregation	(h_2/h_1)	0.8	1.0	0.83
U-Box	Passing and segregation	(h_2-h_1)	0.0	30.0	10.20
V-funnel	Filling ability	sec	6.0	12.0	9.80

Tests conducted on hardened M30 SCC

Compressive strength: For compressive strength cubes of 150×150×150 mm were cast from reference mix of SCC and kept for different types of curing up to 90 days. Three specimen were tested after 3, 7, 28, 56 and 90 days using a calibrated compression testing machine of 2,000 KN capacity as per IS 516 (1959).

$$\text{Compressive strength } f_c = P/A \quad (1)$$

Where:

P = Load

A = Area of cube (a)

RESULTS AND DISCUSSION

Tests results of fresh SCC: The overall fresh SCC properties of reference mix are shown in Table 5. The various tests namely slump flow, L-Box, U-Box and V-funnel were conducted on fresh SCC reference mix as per EFNARC guidelines. The slump flow test has spread of 620 mm. The limiting parameters specified by EFNARC and the results are noted in Table 5. It can be observed that the reference mix satisfies all the criteria as per standards specified by EFNARC.

Compressive strength for M30 SCC: The average compressive strength for various specimens at different ages and selected curing methods for M30 SCC is summarized in Table 6.

Table 6: Compressive strength N mm^{-2} for selected methods of curing for M30 SCC

		Compressive strength N mm^{-2} (days)				
Method/acronym	Results	3	7	28	56	90
Immersion M3I						
	C1	18.3	30.5	35.3	40.1	44.5
	C2	18.7	32.7	35.8	39.2	43.2
	C3	19.6	31.4	33.6	41.9	46.2
	Average	18.9	31.5	34.9	40.4	44.6
	SD	0.7	1.1	1.2	1.3	1.5
Hot water M3H						
	C1	0.0	0.0	33.1	0.0	0.0
	C2	0.0	0.0	32.7	0.0	0.0
	C3	0.0	0.0	34.0	0.0	0.0
	Average	0.0	0.0	33.3	0.0	0.0
	SD	0.0	0.0	0.7	0.0	0.0
Ice M3B						
	C1	17.4	23.1	27.5	32.3	37.5
	C2	16.6	21.8	28.3	32.7	36.2
	C3	17.9	20.9	29.6	34.0	38.8
	Average	17.3	21.9	28.5	33.0	37.5
	SD	0.7	1.1	1.1	0.9	1.3
Sea water M3S						
	C1	18.7	31.8	34.0	39.7	44.9
	C2	21.4	33.1	33.6	38.8	44.5
	C3	20.9	31.0	31.8	38.4	41.9
	Average	20.3	32.0	33.1	38.9	43.7
	S.D	1.4	1.1	1.2	0.7	1.7
Wet covering M3W						
	C1	20.9	29.6	32.3	38.4	44.0
	C2	20.5	30.5	32.7	37.1	43.2
	C3	21.8	29.2	30.5	38.8	44.5
	Average	21.1	29.8	31.8	38.1	43.9
	SD	0.7	0.7	1.2	0.9	0.7

It is widely accepted that strength at 28 days is considered as governing strength for concrete mix design. It is observed that for M30 SCC, immersion method for curing gives maximum ompressive strength 34.9 N mm^{-2}, at 28 days, however 90 days strength is 44.6 N mm^{-2} which is 27.9% >28 days strength. The good compressive strength can be attributed to proper hydration of cement and reduction in voids due to presence of pozzlonic material like fly ash. The results are in confirmation of the results of the study by Safiuddin *et al*. (2007).

Hot water curing gives about 95% strength than immersion curing within short period of time. With increased temperature of water during curing, maturity attained is higher which contributes to more strength in less time.

The lowest strength is for ice curing 28.5 N mm^{-2}, about 81% of immersion curing. This is due to the reason that at around -3 to -4°C, enough of the pore water will freeze so that hydration will completely stop (W.R. Grace & Co. Conn., 2006).

Sea water curing gives second highest strength about 95% of immersion method at 28 days. It can be observed that SCC is little affected by curing with sea water at later age. This is due to the reason that aggressive salt ions penetrate into the interior portion of the concrete mass and change the hydration mechanism with the formation of some expansive products, such as ettringtie or frields salt and some leachable/soft compounds. As a result, micro cracks develop within the concrete mass together with leaching action of the newly formed compounds lead to the deterioration of concrete strength. However, early age strength gain in sea water is more than water immersion method. This may be due to the accelerating effects of some of the sea salts like NaCl, K_2SO_4 which cause a more rapid dissolution of compounds of cement particularly tricalcium silicate in water and hence facilitates more rapid hydration of concrete. This is in confirmation with Islam *et al*. (2012), who noted that the concrete specimens made by mixing sea water and cured in plain/sea water shows higher strength deterioration compared to plain water made and cured concrete for relatively longer period of curing.

This indicates that for extreme weather conditions SCC can prove effective for hot weather and sea water conditions while cold weather does not cater sufficient strength.

Wet covering gives 31.8 N mm^{-2}, about 91% at 28 days. The higher strength may be attributed to availability of enough moisture for hydration process throughout the curing period.

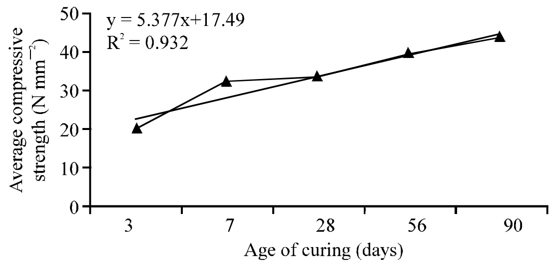

Fig. 1: Relation between compressive strength and age of curing for water immersion curing for M30 SCC

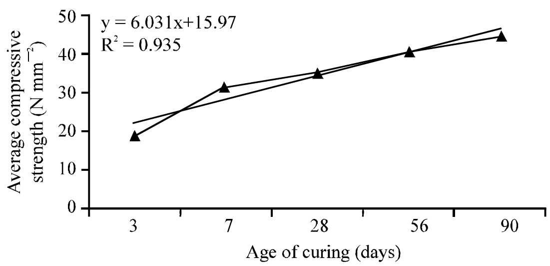

Fig. 2: Relation between compressive strength and age of curing for sea water curing for M30 SCC

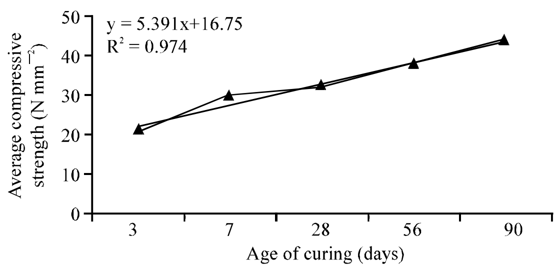

Fig. 3: Relation between compressive strength and age of curing for ice curing for M30 SCC

Relation between compressive strength and curing technique for M30 SCC: The compressive strength was correlated with age of curing for the different methods of curing by regression analysis using Microsoft Excel Software. Figure 1-4 shows correlation between compressive strength and age of curing for immersion and other curing techniques for M30 SCC.

For immersion curing the best-fit line exhibited a linear relationship between the compressive strength ranging from 22.0-46.1 N mm^{-2}. The coefficient of determination for the best-fit line was 0.9357 and the correlation coefficient was 0.967. A similar relationship between the compressive strength and curing of concrete was noticed by other researchers (Al-Feel and Al-Saffar, 2009; Kumar *et al*., 2012).

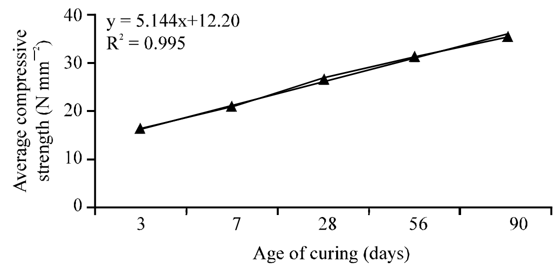

Fig. 4: Relation between compressive strength and age of curing for wet covering for M30 SCC

For sea water curing, the best-fit line exhibited a linear relationship between the compressive strength ranging from 22.9-44.4 N mm^{-2}. The coefficient of determination for the best-fit line was 0.933 and the correlation coefficient was 0.966 (Fig. 2).

For ice curing, the results exhibited a linear relationship between the compressive strength ranging from 17.4-37.9 N mm^{-2}. The coefficient of determination for the best-fit line was 0.9953 and the correlation coefficient was 0.9976. These values of correlation coefficients show a very good compatibility between two specified properties (Fig. 3).

For wet covering curing the results exhibited a linear relationship between the compressive strength ranging from 22.15-43.72 N mm^{-2}. The coefficient of determination for the best-fit line was 0.9747 and the correlation coefficient was 0.9873. These values of correlation coefficients show quite good compatibility between two specified properties (Fig. 4).

It can be concluded that for M30 SCC, compressive strength increases with age of curing and the rate of increase depends on techniques used for curing of concrete. At 28 days the highest strength achieved through immersion method of curing is 34.9 N mm^{-2} and the lowest strength with ice curing is 28.5 N mm^{-2}, about 81% of highest strength. In all the techniques prolonged curing adds to compressive strength of concrete.

Correlation between compressive strength with immersion method and other selected curing technique for M30 SCC: The compressive strength achieved with immersion method was correlated with compressive strength results with other selected methods of curing by regression analysis using Microsoft Excel Software.

Figure 5, exhibits the correlation between compressive strength of immersion curing and other selected methods of curing in which water is used as supplementary curing medium for M30 SCC. The correlation equation for best fit line, the coefficient of

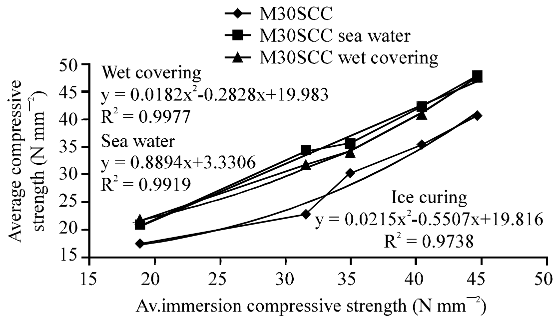

Fig. 5: Correlation between compressive strength with immersion method and other selected curing technique for M30 SCC; vs, ice/sea water wet

determination and the correlation coefficient is displayed on the graph. These values of correlation coefficients show a good compatibility between two specified properties.

CONCLUSION

- It has been verified by using the slump flow, U-tube tests and other tests on fresh SCC that Self-Compacting Concrete (SCC) achieved consistency and self-compactability under its own weight without any external vibration or compaction
- It is concluded from mention earliar study that method of curing has considerable effect on the compressive strength of SCC
- Immersion curing gives best result for curing in SCC while ice curing is observed to be the weakest
- Hot water curing can give good compressive strength within short period of time. This method can prove beneficial in precast industry
- Sea water when used for curing of SCC may give higher compressive strength at early age but prolonged curing gives strength lesser than conventional water immersion method
- Wet covering method of curing gives almost parallel compressive strength to immersion method strength with saving in water

REFERENCES

Agullo, L., B. Toralles-Carbonari, R. Gettu and A. Aguado, 1999. Fluidity of cement pastes with mineral admixtures and superplasticizer-A study based on the Marsh cone test. Mater. Struct., 32: 479-485.

Al-Feel, J.R. and N.S. Al-Saffar, 2009. Properties of self compacting concrete at different curing condition and their comparison with properties of normal concrete. Al-Rafidain Eng., 17: 30-38.

CCAA., 2006. Curing of concrete: A data sheet. April 2006, Cement Concrete and Aggregates Australia. http://www.concrete.net.au/publications/pdf/Curing06.pdf.

EFNARC., 2002. Specification and guidelines for self-compacting concrete. European Federation of Producers and Applicators of Specialist Products for Structures. http://www.efnarc.org/pdf/SandGfor SCC.PDF.

IS 516, 1959. Methods of Tests for Strength of Concrete. Bureau of Indian Standards, New Delhi, India.

IS 456, 2000. Plain and Reinforced Concrete-Code of Practice. 4th Edn. Rev., Bureau of Indian Standards, New Delhi, India, Pages: 27.

Islam, M.M., M.S. Islam, M. Al-Amin and M.M. Islam, 2012. Suitability of sea water on curing and compressive strength of structural concrete. J. Civil Engin., (IEB), 40: 37-45.

Khayat, K.H., C. Hu and H. Monty, 1999. Stability of self-consolidating concrete, advantages and potential applications. Proceedings of 1st International RILEM, Symposium on Self-Compacting Concrete, September, 2013, RILEM Publications SARL., pp: 143-152.

Kumar, M.V.J., M. Srikanth and R.K. Jagannadha, 2012. Strength characteristics of self-curing concrete. Int. J. Res. Eng. Technol., 1: 51-57.

Kumbhar, P.D., Rajaramnagar and P. Murnal, 2011. Effect of humidity and temperature on properties of high performance concrete. NBM Construction Information, New Delhi, India. May, 2011.

Qureshi, L.A., I.A. Bukhari and M.J. Munir, 2010. Effect of different curing techniques on compressive strength of high strength self compacting concrete. Bahaudin Zakriya University, Multan Pakistan.

Safiuddin, M., S.N. Raman and M.F.M. Zain, 2007. Effect of different curing methods on the properties of microsilica concrete. Aust. J. Basic Appl. Sci., 1: 87-95.

Shetty, M.S., 2005. Concrete Technology-Theory and Practice. Chand, S. and Company, New Delhi, India, Pages: 624.

Stegmaier, M., 2005. Heat curing of self-compacting concrete. Otto Graf J., 16: 167-183.

Vijai, K., R. Kumutha and B.G. Vishnuram, 2010. Effect of types of curing on strength of geopolymer concrete. Int. J. Phys. Sci., 5: 1419-1423.

W.R. Grace & Co. Conn., 2006. Cold weather concrete. Technical Bulletin TB-0106. http://www.na.graceconstruction.com/custom/concrete/downloads/TB_0106.pdf.