Nova Scotia Department of Natural Resources

(15) Crown Land Site

PROSPECTOR'S STATEMENT AR97-084

Form No. 11

RE EXPLORATION LICENCE NO. 2589

Date First Issued Aug. 28 1996

PROPERTY LOCATION (Hiltz Rd.) Crown Land Site COUNTY Kings

Have you filed a prospector's Statement regarding this property before?
☑ No ☐ Yes - Provide dates (month/year): ______
(N.B. Only new information is acceptable for work credits)

CLAIMS	TRACT	CLAIM REF. MAP	CLAIMS	TRACT	CLAIM REF. MAP
N, O, P	107	21 H2A			
F, J, K, L, Q	108	"			
B, C, D, F	11	21 H2D			

1. Did you search the property for outcrop ☐ float ☐ or both ☑ ?

2. Was your search carried out:
a) along roads and/or streams? ☑ No ☑ Yes - Identify such features on your map.
b) on control or traverse lines? ☑ No ☐ Yes - Indicate if blazed ☐, flagged ☐ or unmarked ☐ ______ and how established (compass, chain, pace etc.) and show the approximate location of the lines on your map.

3. Are your compass bearings magnetic ☐ or true astronomic ☑ ?

4. Did you carry out any trenching/pitting? ☑ No ☑ Yes
stripping? ☑ No ☐ Yes
drilling? ☑ No ☐ Yes
- if so, show the location of these workings on your map and indicate their dimensions
- briefly state your reason for locating these workings where you did

5. Did you locate any previously existing shafts or adits? ☑ No ☐ Yes,
drillhole sites? ☑ No ☐ Yes
- if so, indicate these on your map.

6. Record the types of the rocks your observed
a) in outcrop: heulandite, stilbite, scolecite
b) in float: same

DUPLICATE AVAILABLE

7. Did you measure the strike/trend and dip of:
a) the rocks in place? ☑ No ☐ Yes
b) of any observed veins ☑ No ☐ Yes
- if YES to either, plot these observations on your map(s).

8. Did you observe any mineralization on the property? ☐ No ☑ Yes
- if YES indicate
a) locations and type on your map(s) with symbols (Py, Au etc.)
b) the character and width of observed veins, e.g.: "quartz (Q)/3.3 ft. (or 1.0M).

9. Did you sample any:

a) overburden (soil or till)?	☑ No	☐ Yes	b) outcrop or float?	☐ No	☑ Yes
b) panning concentrate?	☑ No	☐ Yes	d) dumps/tailings?	☑ No	☐ Yes
c) mine workings?	☑ No	☐ Yes	e) drill core/cuttings?	☑ No	☐ Yes

10. Did you have any samples analyzed? ☐ No ☐ Yes
- if YES, indicate the nature (grab or chip etc.) and width (ft. or m) of the sample, plot the result on your map and attach original assay sheet(s) from the laboratory.

- of NO, explain why not ______________________

11. Record any other observations that you consider significant (here or upon your map):
see attached

12. The NAMES and ADDRESSES of the persons who performed the said work and the DATES upon which each person worked in its performance are as follows:

NAME	ADDRESS	MONTH	DATES
Ian Booth			
NRC Labs			
Polar Powders			

THE TOTAL COST OF THE WORK REPORTED BY THIS STATEMENT IS $ 2475
(ref. Statement of Expenditure filed separately)

I HEREBY CERTIFY THAT THE INFORMATION RECORDED ABOVE AND ON THE ATTACHED MAP(S) IS, TO THE BEST OF MY KNOWLEDGE, TRUE AND CORRECT

Dated at Halifax
this 27 day of August 1997

Signature of Licensee

FOR DEPARTMENT USE			
Received		Conf. to	
Accepted		Filed	
Rejected		Exp. Mon	
Returned		D/Base	
Recorded			

	'Crown Land' Site	
License #:	02589	
Map:	21 H 2 A:	
	107 N, O, P;	
	108 F, J, K, L, Q	
	21 H 2 D:	
	11 B, C, D, F	12 Claims in Total

Site Description:
This license includes the largest piece of Crown Land on the central North Mountain. It is densely wooded and surrounded on all four sides by roads, mostly unpaved. The land is underutilized and there are few neighbours.

Work Performed:
Initial field prospecting indentified roadside zeolitic outcrops all around the Crown Land. Our site work suggested that almost this entire license overlies a shallow and readily accessible heulandite deposit of large volume and good grade.

This zone appears to be laterally continuous along strike and dip for a considerable distance. Whereas lateral continuity along strike is commonplace along the Blomidon Flow, such broad north-south exposures along dip are rare. At such sites, the zeolite layer lies close to the surface, because the dip of the surface parallels the dip of the flow top. (The Huntington Point Road Area is a similar location.)

A shallow zeolite zones with minimal overburden improves the economics and dramatically increases the maximum economic reserve size. (The Arlington Site represents the opposite extreme, where barren overburden sharply curtails the size of the economic zeolite reserve.)

These 'Crown Land' zeolitic exposures are apparently an extension of the same Blomidon Flow exposed along strike to the east at the Huntington Roint Road site, and to the west at the Stronach Mountain Quarry.

We believe this 'Crown Land' site contains the standard zeolitic mix, which is primarily heulandite, that is typical at other Blomidon Flow exposures. What differentiates this 'Crown Land' location are its unique advantages of potential large volume, easy access and Crown ownership.

Future research will determine if the zeolite exposures surrounding these claims are multiple outcrops of the same flow top. This would confirm whether the central area of this license overlies a continuous, and extensive shallow zeolite deposit.

Optimistically, this license could contain an accessible zeolite reserve of 450,000 tonnes of zeolite. (Based on a rough calculation using the following description: 1500 m (along strike) x 500 m (along dip) x 4 m (deep) x 10 % (zeolite) x 1.5 tonne/cubic meter of zeolite = 450,000 tonnes of commercial zeolite.)

Conclusions:
This "Crown Land' site appears to be one of our very best on the North Mountain. This site has an apparent potential for a large scale zeolite production operation, with a annual output capacity over 20,000 tonnes.

A thorough drilling program is planned for this license in the fall of 1997 to delineate the reserve size and to estimate production costs.

Research Study Work Assigned to this License:
We commisioned a detailed research program through Polar Powders, in association with the NRC, to determine the potential application of zeolitic rock dust in the manufacture of lightweight concretes. This technology is already proven, but has never before been applied to Nova Scotian material.

Creating a market for crushed stone by-product is key to the profitable operation of any future Nova Scotian zeolite quarry. Without cost recovery from the by-product, the profitability of any future North Mountain zeolite quarry would be doubtful.

(There is no crushed rock by-product generated by US zeolite production. The US deposits are homogeneous beds of impure zeolite, about 40%, which cannot be upgraded. These US sites have a lower production cost than NS sites, but produce an inferior final product for most applications.)

We are researching three such potential applications for zeolitic rock-dust by-product. This report examines the first of these, the utilization of Nova Scotian zeolites in the manufacture of lightweight concrete.

We believe the magnetic portion of the crushed ore, the by-product after magnetic separation, still apparently contains about 5-15% zeolite, by weight. This by-product has a CEC of 30 or more, 1/3 the quality of US zeolite. This creates potential markets in applications where zeolites are mixed with rock dust or sand.

Concrete products made with US zeolite, are known to be preferable to regular concrete, but have a higher production cost, due to the zeolitic ingredient. However, an exciting conclusion of the attached study is that Nova Scotian by-product works almost as well in lightweight concrete as does pure US zeolite costing $300/ton or more.

This lightweight concrete application requires further study, but clearly enhances the economic potential for most Nova Scotian zeolite deposits.

Corrections:

1) The sample descriptions on page 10 of the report are incomplete. The NS ore samples Z1, Z2, and Z3 probably contained no chabazite. (This mineral was identified in the basal Blomidon Flow by a previous researcher (Bray), but we conclude it does not occur here. This is unfortunate, because chabazite is more valuable than the other zeolites. We have never found even 1g. of chabazite along the Blomidon Flow in five years of field work, whereas chabazite is abundant on the Parrsboro Shore at several locations, and sparingly on Digby Neck. It may also occur sparingly to the west near Hampton, and to the east near Cape Blomidon.)

2) Z1 was collected from the eastern section of our study area. It was a mix of zeolitic basalt 'ore', gathered from several roadside sites from the Harbourville Road east to the Ross Creek Road. These sites are all in the basal Blomidon Flow of the North Mountain, or from one of the two other lowest flows. Our subsequent research indicates concentrates from these zeolite ores are more likely a mix of heulandite(75%), stilbite (20%), and scolecite and other zeolites(5%). Our estimated CEC for the concentrate from this mix is 159.

3) Z2 was a similar material from the western section of the Blomidon Flow only, from the Stronach Mountain Road east to the Harbourville Road. This zeolite ore likely contains a zeolite ratio of heulandite(85%), stilbite (10%), and scolecite and other zeolites(5%). Our estimated CEC for the concentrate from this mix is 135.

4) Z3 was collected from the middle and upper flows and likely had higher content of stilbite. This would mean a higher CEC material. The concentrate had a probable zeolite ratio of stilbite(75%), heulandite (15%), and stellarite, epistilbite and other zeolites(10%). Our estimated CEC for the concentrate from this mix is 179.

Allocation of Report Costs:
For this license, we will assign a pro-rated 10% proportion of the cost of the attached study based on the number of claims involved and the relative reserve size.

The remaining costs of the lightweight concrete study will be allocated this fall of 1997 to our other key sites for which this research applies. We will allocate the total costs of this research to about 110 claims being renewed in the next three months. These claims all lie directly within the zone for which the tested materials are representative of the zeolite concentrate that probably can be produced on that claim.

Fot future researchers, we define the sole zones for which these results apply as:
a) the continuous exposure of the Blomidon Flow from Stronach Mountain Road East to the Ross Creek Road,
b) the middle flows east from the Bishop Mountain Road to the Huntington Road, and
c) the upper flows east from French Cross to Huntington Point.
d) or any other sites for which the zeolite concentrate obtained is primarily heulandite or stilbite.

Areas excluded are sites along Digby Neck, the Parrsboro Shore, or any sites for which the main zeolite is chabazite, analcite, natrolite, mordenite or mesolite. This technology would be unsuitable for such locations; it probably won't work for natrolite, analcite or mesolite sites, and a higher value use exists for chabazite and (probably) mordenite sites.

There are probably 500 open claims within the applicable zone for which these report results would also apply, but which now appear less attractive production sites. We leave these claims open to other companies and hope the attached report will assist them when the results are made publically available in two years. Good luck !

'Crown Land' Site - Assessment Work

Attached NRC Report:	
Pro-Rated Cost (1/10 x $20,000)	$2000
Field Work:	
2 visits (1.5 day total)	75
Transportation:	
500 km. @ $.30/km.	150
Allocated Overhead	220
Crown Land Work Total	**$2475**

'Crown Land' Site (13)

Nova Scotia Department of Natural Resources

Form No. 10

MAP REFS. 21 H 2A | 21 H 2 D; 107 N, O, P | Tract 11; 108 F, J, K, L, Q | B, C, D, F

STATEMENT OF ASSESSMENT WORK EXPENDITURES

(N.B. Complete as necessary to substantiate the total claimed)

RE: EXPLORATION LICENCE NO. 2589 DATE OF ISSUE Aug 28 1996

TYPE OF WORK			AMOUNT SPENT
1. Prospecting	1 1/2	days	75
2. Geological mapping		days	
3. Trenching/Stripping/Refilling		m^2	
4. Assaying & whole rock analysis		#	
5. Other laboratory		#	
6. Grid: a) Linecutting		km	
b) Picket setting		km	
c) Flagging		km	
7. Geophysical Surveys: Airborne: a) EM		km	
b) Mag or Grad		km	
c) Radiometric		km	
d) Combination		km	
e) Other		km	
8. Geophysical Surveys: Ground: a) EM		km	
b) Seismic Soundings		#	
c) Magnetic/telluric		km	
d) IP/Resistivity		km	
e) Gravity		km	
f) Other		km	
9. Geochemical Surveys: a) Lake, stream, spring (seds/water)		samples	
b) Rock/core/chips		samples	
c) Soil/Overburden		samples	
d) Gas Method		samples	
e) Biogeochemistry		samples	
f) Sample Collection		days	
g) Other			
10. Drilling: a) Diamond (#holes/m)	/	m	
b) Percussion (#hole/m)	/	m	
c) Rotary (#hole/m)	/	m	
d) Auger (#holes/m)	/	m	
e) Reverse circulation (#holes/m)	/	m	
f) Logging, supervision etc.	/	days	
g) Sealing (# holes)			
11. Other: (describe) transport.	500 km @ $.30		150
Report attached			2000
		SUBTOTAL	

AUG 28 12 23 PM '97

OVERHEAD COSTS	
12. Secretarial Services	
13. Drafting Services	
14. Office Expenses (rent, heat, light etc.)	
15. Field Supplies	
16. Compensation Paid to Landowners	
17. Legal Fees	
18. Other (describe) misc. overhead	220
SUBTOTAL	
TOTAL	2475

I hereby certify that the above information is true and correct and that it has not before been submitted for assessment work credit.

As Ground - person I am duly authorized to make this certification.
(Position in Company or Licensee)

DATED AT Halifax in the Province of Nova Scotia

this ______ day of August 19 97

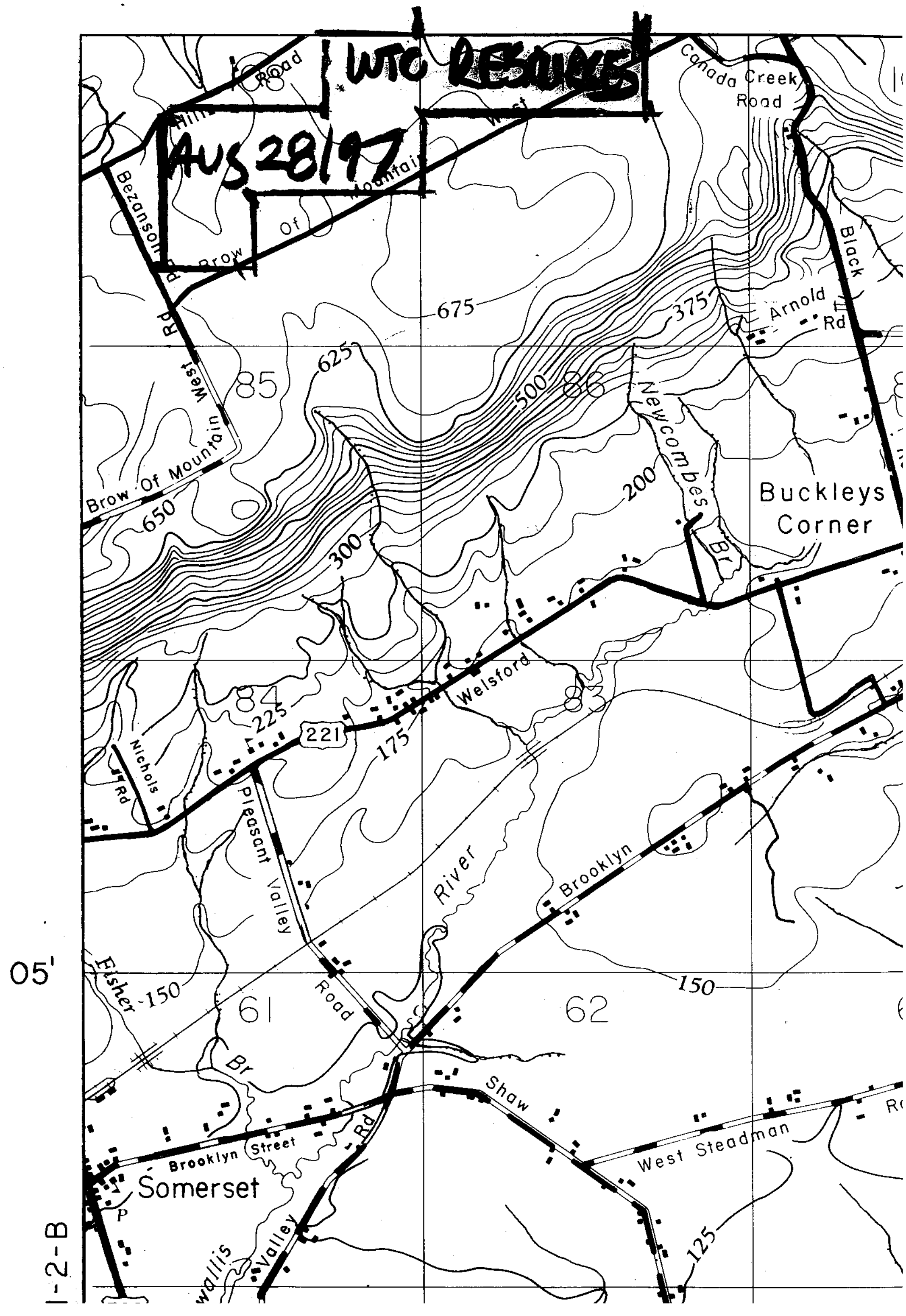
Name and Address of Licensee: WTC Resources Ltd. c/o Van Rennsel[?]

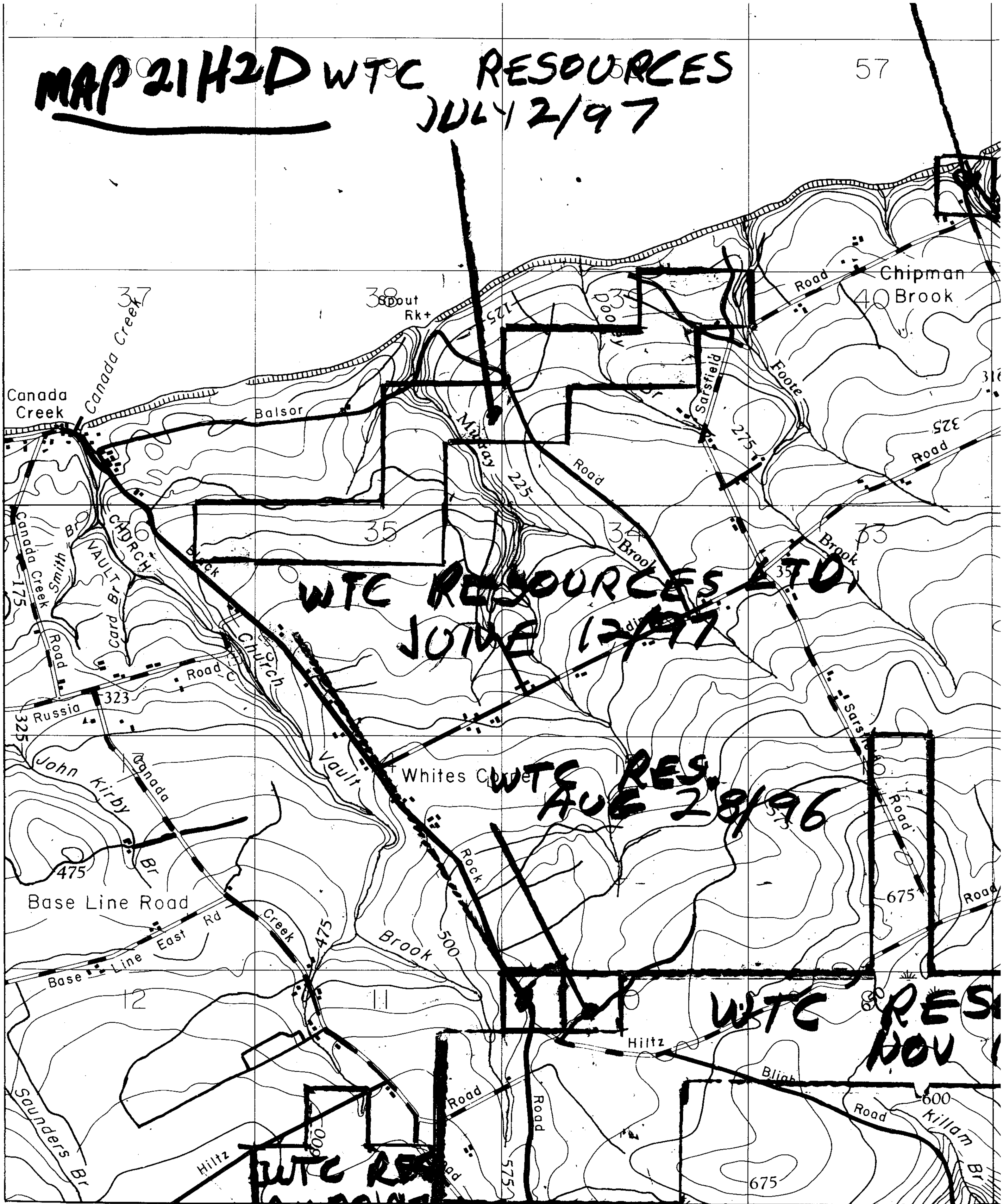
Signature Ian Booth

MAP 21H2A

64°45'

BERWICK





First Edition 28/3/79 fr... taken in 1967

UNIVERSAL TRANSVERSE MERCATOR PROJECTION

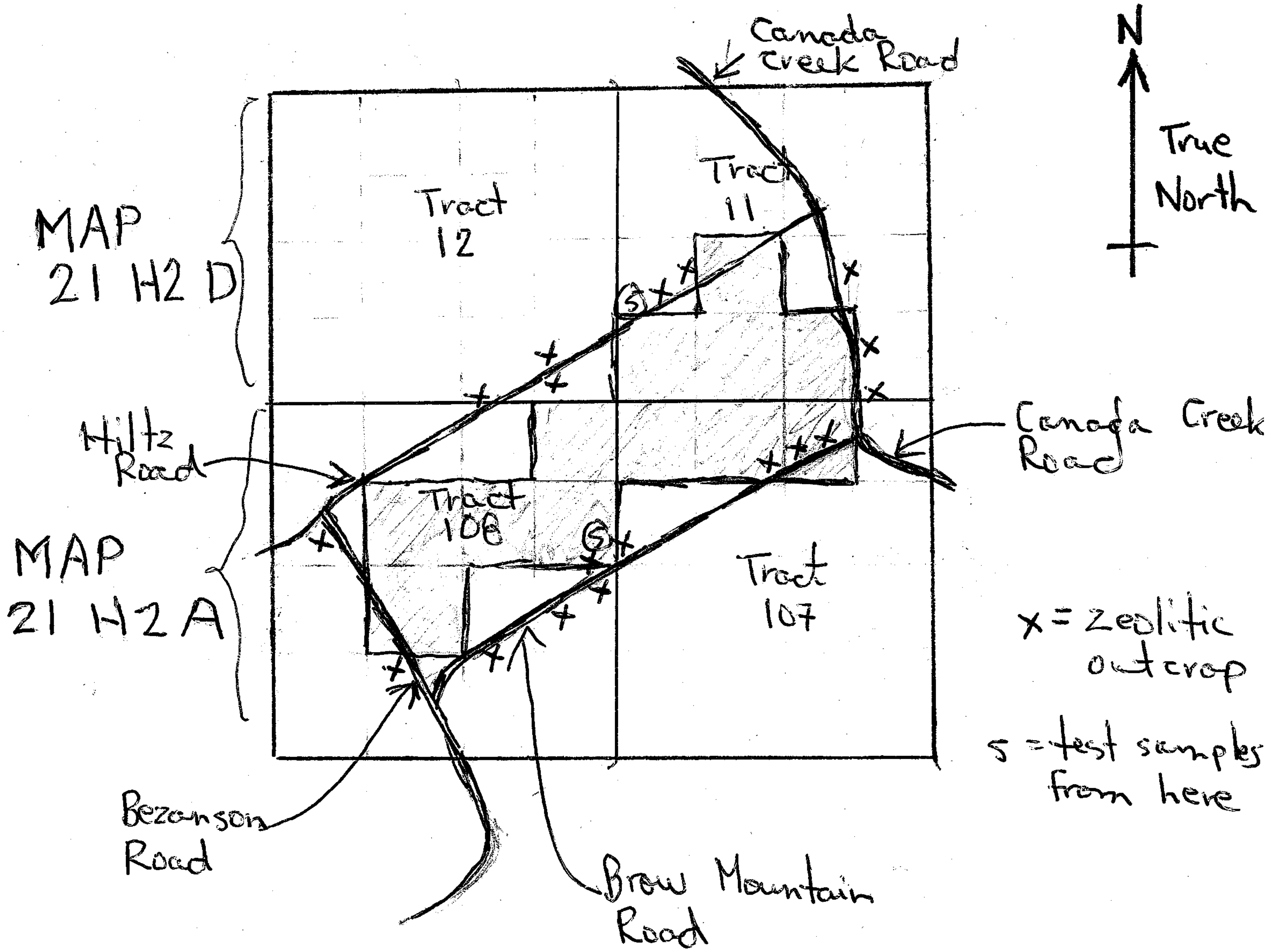
45'

40

Name: 'Crown Land' Site

License: 2589

	21 H2A		+	21 H2D
Map:	21 H2A		+	21 H2D
Tract:	107	108		11
Claim:	N, O, P	F, J, K, L, Q		B, C, D, F



Scale

2 ~~3/4~~ miles

1 inch = 660 feer

National Research Council Canada
Conseil national de recherches Canada

NRC-CNRC

Client Report

A-2645.1

Steam-Cured Zeolite-Based Concrete Products

for

Polar Powders & Technologies Inc.
Box 76011
70 Shawville Boulevard S.W.
Calgary, Alberta
T2X 2Z9

13 August 1996

Steam-Cured Zeolite-Based Concrete Products

Final Report

Author J.J. Beaudoin

Author(s)

Approved Dr. J.J. Beaudoin
Head,
Materials Laboratory

Report No.: A-2645.1
Report Date: August 13, 1996
Contract No.: A-2645
Reference: Application for test dated 6 June, 1996

61 pages
Copy 4 of 4 copies

Summary

A series of concrete formulations using Nova Scotia and US zeolite rocks was evaluated. The products contained pulverized zeolite, portland cement, zeolite rock aggregate, plaster of Paris and quick lime. The products were initially moist-cured at 65-85 °C and then stored at room temperature and about 50% R.H. The effect of cement, aggregate and plaster content, on compressive strength, dry density, drying shrinkage and water adsorption of these products was determined. The effect of different curing temperatures and periods was also investigated. Recommendations for further research and industrial manufacture of steam-cured zeolite concrete products are provided.

Contents

Tables

Figures

Fig. 1. Effect of cement content on compressive strength of concretes made with zeolite z-1 (initially cured at 85 °C and 100% R.H. for 16 hours and then stored at 23 °C and 50% R.H.).

Fig. 2. Effect of cement content on compressive strength of concretes made with zeolite z-2 (initially cured at 85 °C and 100% R.H. for 16 hours and then stored at 23 °C and 50% R.H.).

Fig. 3. Effect of cement content on compressive strength of concretes made with zeolite z-3 (initially cured at 85 °C and 100% R.H. for 16 hours and then stored at 23 °C and 50% R.H.).

Fig. 4. Effect of cement content on compressive strength of concretes made with volcanic z-4 (initially cured at 85 °C and 100% R.H. for 16 hours and then stored at 23 °C and 50% R.H.).

Fig. 5. Effect of cement content on compressive strength of concretes made with volcanic z-5 (initially cured at 85 °C and 100% R.H. for 16 hours and then stored at 23 °C and 50% R.H.).

Fig. 6. Effect of cement content on compressive strength of concretes made with zeolite z-6 (initially cured at 85 °C and 100% R.H. for 16 hours and then stored at 23 °C and 50% R.H.).

Fig. 7. Effect of cement content on compressive strength of concretes made with zeolite z-7 (initially cured at 85 °C and 100% R.H. for 16 hours and then stored at 23 °C and 50% R.H.).

Fig. 8. Effect of cement content on compressive strength of concretes made with volcanic z-8 (initially cured at 85 °C and 100% R.H. for 16 hours and then stored at 23 °C and 50% R.H.).

Fig. 9. Effect of cement content on compressive strength of concretes made with zeolite z-9 (initially cured at 85 °C and 100% R.H. for 16 hours and then stored at 23 °C and 50% R.H.).

Fig. 10. Effect of cement content on compressive strength of concretes made with zeolite z-10 (initially cured at 85 °C and 100% R.H. for 16 hours and then stored at 23 °C and 50% R.H.).

Fig. 11. Effect of aggregate content on compressive strength of concretes made with zeolite z-1 (initially cured at 85 °C and 100% R.H. for 16 hours and then stored at 23 °C and 50% R.H.).

Fig. 12. Effect of aggregate content on compressive strength of concretes made with zeolitez-2 (initially cured at 85 °C and 100% R.H. for 16 hours and then stored at 23 °C and 50% R.H.).

Fig. 13. Effect of aggregate content on compressive strength of concretes made with zeolite z-3 (initially cured at 85 °C and 100% R.H. for 16 hours and then stored at 23 °C and 50% R.H.).

Fig. 14. Effect of plaster content on compressive strength of concretes made with zeolite z-1 (initially cured at 85 °C and 100% R.H. for 16 hours and then stored at 23 °C and 50% R.H.).

Fig. 15. Effect of plaster content on compressive strength of concretes made with zeolite z-2 (initially cured at 85 °C and 100% R.H. for 16 hours and then stored at 23 °C and 50% R.H.).

Fig. 16. Effect of plaster content on compressive strength of concretes made with zeolite z-3 (initially cured at 85 °C and 100% R.H. for 16 hours and then stored at 23 °C and 50% R.H.).

Fig. 17. Effect of cement content on compressive strength of concretes made with zeolite z-1 (initially cured at 65 °C and 100% R.H. for 16 hours and then stored at 23 °C and 50% R.H.).

Fig. 18. Effect of cement content on compressive strength of concretes made with zeolite z-2 (initially cured at 65 °C and 100% R.H. for 16 hours and then stored at 23 °C and 50% R.H.).

Fig. 19. Effect of cement content on compressive strength of concretes made with zeolite z-3 (initially cured at 65 °C and 100% R.H. for 16 hours and then stored at 23 °C and 50% R.H.).

Fig. 20. Effect of aggregate content on compressive strength of concretes made with zeolite z-1 (initially cured at 65 °C and 100% R.H. for 16 hours and then stored at 23 °C and 50% R.H.).

Fig. 21. Effect of plaster content on compressive strength of concretes made with zeolite z-1 (initially cured at 65 °C and 100% R.H. for 16 hours and then stored at 23 °C and 50% R.H.).

Fig. 22. Effect of high temperature curing period on compressive strength of concretes made with zeolite z-1 (initially cured at 85 °C and 100% R.H. for 16 hours and then stored at 23 °C and 50% R.H.).

Fig. 23. Effect of content of air entraining agent on compressive strength of concretes made with zeolite z-1 (initially cured at 85 °C and 100% R.H. for 16 hours and then stored at 23 °C and 50% R.H.).

Fig. 24. Effect of cement content on drying shrinkage of concretes stored at 23 °C and 50% R,H. (made with zeolite z-1 and initially cured at 85 °C and 100% R.H.).

Fig. 25. Effect of cement content on drying shrinkage of concretes stored at 23 °C and 50% R,H. (made with zeolite z-2 and initially cured at 85 °C and 100% R.H.).

Fig. 26. Effect of cement content on drying shrinkage of concretes stored at 23 °C and 50% R,H. (made with zeolite z-3 and initially cured at 85 °C and 100% R.H.).

Fig. 27. Effect of aggregate content on drying shrinkage of concretes stored at 23 °C and 50% R,H. (made with zeolite z-1 and initially cured at 85 °C and 100% R.H.).

Fig. 28. Effect of plaster content on drying shrinkage of concretes stored at 23 °C and 50% R,H. (made with zeolite z-1 and initially cured at 85 °C and 100% R.H.).

Fig. 29. Effect of cement content on water absorption by concretes made with zeolite z-1 or z-3.

Fig. 30. Effect of cement content on water absorption by concretes made with zeolite z-9 or z-10.

Fig. 31. Effect of aggregate content on water absorption by concretes made with zeolite z-1.

Fig. 32. Effect of plaster content on water absorption by concretes made with zeolite z-1.

Fig. 31. Effect of air entraining agent on water absorption by concretes made with zeolite z-1.

§ 1. Introduction

§ 1.1. Background

Conventional lightweight concrete products are made of cement and/or lime, together with slag, pulverized fuel-ash, and other siliceous fine aggregates. Zeolite is a porous silicoaluminate mineral with low density. It can react with calcareous materials to form calcium silicoaluminate hydrates which contribute to the strength of the concrete. Zeolite has the potential for use as a basic raw material for production of lightweight concrete products. This is clearly described in an IRC patent "Zeolite Based Lightweight Concrete Products" (US Patent No 5,494,513, 1996).

A series of formulations to produce autoclaved lightweight concrete products for the construction of agricultural or light industrial buildings in aggressive environments have been developed. The products contain natural zeolite, silica sand, silica flour, Portland cement and quick lime. The effect of each component on compressive strength and dry density of these products was determined.

§ 1.2. Objectives

The objective of this research was to determine the potential for utilization of three Nova Scotia zeolite rocks and two US natural zeolites for the production of zeolite - based concrete products.

§ 2. Test Program

§ 2.1. Materials

The materials used in this test program included:

(1) Natural zeolite rocks (supplied by Polar Powder Technologies Inc., Calgary, Alberta, Canada). These were used as a major cementitious material to make zeolite-based concretes.

Three of the zeolite rocks were from the North Mountain area of Nova Scotia. The North Mountain area is comprised of a series of basaltic flow rocks of the Acadian Triassic period and are referred to as the North Mountain Basalts. The maximum elevation of the "mountain" is approximately 250 meters. The zeolite rocks contain about 15-20% zeolites and 80-85% volcanics by mass. In general, the zeolites are stilbite, chabazite, heulandite, clinoptilolite and/or scolecite. The zeolites can be easily extricated from the rocks by magnetic separation. Both separated zeolites and volcanics were used in this study (see Table 1).

Two natural zeolites from Texas and New Mexico, USA, were also tested. The zeolites were mainly clinoptilolite.

The different zeolite rock samples investigated are identified in Table 1.

Table 1. Samples of Volcanic Rocks and Zeolite Rocks

Samples	Sources	Main Mineralogical Composition	Color
z-1	Huntington, Nova Scotia.	Volcanics, chabazite, heulandite, clinoptilolite, scolecite, etc.	Brown
z-2	Arlington, Nova Scotia.	Volcanics, chabazite, heulandite, clinoptilolite, scolecite, etc.	Brown
z-3	Stronach, Nova Scotia.	Volcanics and Stilbite.	Brown
z-4	Volcanics separated from z-1 (once passing the magnetic fraction).	Volcanics.	Brown
z-5	Volcanics separated from z-1 (twice passing the magnetic fraction).	Volcanics.	Brown
z-6	Zeolites separated from z-2	Chabazite, heulandite, clinoptilolite, scolecite, etc.	White
z-7	Zeolites separated from z-3.	Stilbite.	Pink
z-8	Volcanics separated from z-3 by magnetic fraction.	Volcanics.	Brown
z-9	Texas, USA.	Clinoptilolite.	White
z-10	New Mexico, USA.	Clinoptilolite.	White

(2) Pulverized zeolites volcanics(average particle size: 0.08 mm). These were used as cementitious material in the production of zeolite-based concrete products. They were prepared by grinding the zeolite rock samples listed in Table 1 (z-1 to z-10).

(3) Zeolite rock aggregates. These were prepared by crushing the rock samples (z-1, z-2 and z-3). The aggregates were graded as follows:

Sieve	Percentage Passing
4.250 mm	100
3.327 mm	36
1.651 mm	45
1.168 mm	13
0.290 mm	6

(4) Type 10 Portland Cement supplied by Lafarge Canada Inc.;

(5) Quick lime (CaO) supplied by Anachemia Canada Inc.;

(6) Plaster of Paris ($CaSO_4 \cdot 0.5H_2O$).

(7) A vinsol resin based air entraining agent.

(8) Tap water.

§ 2.2. Mix Design

The mix designs were based on the following considerations:

(1) A basic formulation for steam cured zeolite-based concretes, was selected from the previous study at IRC (Report for Polar Powders Technologies Inc: "Lightweight zeolite-based concrete products for agricultural or light industrial buildings", April, 1994).

Zeolite	Cement	Aggregate	Quick Lime	Plaster of Paris	Water
1	0.1-0.3	1.1-2.2	0.15	0.3-0.8	0.4-0.5

(2) Ten zeolite rocks samples were evaluation. They were the major components in the concrete mix and played a key role as cementitious materials in the development of strength and other engineering properties.

(3) The crushed zeolite rocks and pulverized zeolite powder were used as aggregate in the concrete mixes. This design maximized the utilization of raw materials (rocks) in the production of zeolite concretes.

(4) The optimization of portland cement content in the concretes was studied. The cement content was 10, 20 and 30% by mass of pulverized zeolite.

(5) The optimization of Plaster content in the concretes was also studied. The contents were 0.3, 0.5 and 0.8% by mass of zeolite or volcanics.

(6) Curing temperatures of 65 °C and 85 °C were used.

(7) High-temperature (65-85 °C) curing periods of 5, 9 and 16 hours were used.

(8) Use of an air-entraining agent to reduce the dry density of the concretes was evaluated.

The mixes used in this study are listed in Tables 2 and 3.

Table 2. Mix Design of Zeolite-Based Concretes

Specimen	Zeolite (Type*)	Zeolite Aggregate	Portland Cement	Quick Lime	Plaster of Paris	Water	Air Entraining Agent	Curing Temp (°C)
ZB-1	1 (z-1)	1.10	0.1	0.15	0.05	0.44	-	85
ZB-2	1 (z-1)	1.10	0.2	0.15	0.05	0.48	-	85
ZB-3	1 (z-1)	1.10	0.3	0.15	0.05	0.52	-	85
ZB-4	1 (z-2)	1.10	0.1	0.15	0.05	0.44	-	85
ZB-5	1 (z-2)	1.10	0.2	0.15	0.05	0.48	-	85
ZB-6	1 (z-2)	1.10	0.3	0.15	0.05	0.52	-	85
ZB-7	1 (z-3)	1.10	0.1	0.15	0.05	0.44	-	85
ZB-8	1 (z-3)	1.10	0.2	0.15	0.05	0.48	-	85
ZB-9	1 (z-3)	1.10	0.3	0.15	0.05	0.52	-	85
ZB-10	1 (z-1)	1.65	0.1	0.15	0.05	0.44	-	85
ZB-11	1 (z-1)	2.20	0.1	0.15	0.05	0.44	-	85
ZB-12	1 (z-2)	1.65	0.1	0.15	0.05	0.44	-	85
ZB-13	1 (z-2)	2.20	0.1	0.15	0.05	0.44		85
ZB-14	1 (z-3)	1.65	0.1	0.15	0.05	0.44	-	85
ZB-15	1 (z-3)	2.20	0.1	0.15	0.05	0.44	-	85
ZB-16	1 (z-1)	1.10	0.1	0.15	0.03	0.44	-	85
ZB-17	1 ((z-1)	1.10	0.1	0.15	0.08	0.44	-	85
ZB-18	1 (z-2)	1.10	0.1	0.15	0.03	0.44	-	85
ZB-19	1 (z-2)	1.10	0.1	0.15	0.08	0.44	-	85
ZB-20	1 (z-3)	1.10	0.1	0.15	0.03	0.44	-	85
ZB-21	1 (z-3)	1.10	0.1	0.15	0.08	0.44	-	85
ZB-22	1 (z-1)	1.10	0.1	0.15	0.05	0.44	-	65
ZB-23	1 (z-1)	1.10	0.2	0.15	0.05	0.48	-	65
ZB-24	1 (z-1)	1.10	0.3	0.15	0.05	0.52	-	65
ZB-25	1 (z-2)	1.10	0.1	0.15	0.05	0.44	-	65
ZB-26	1 (z-2)	1.10	0.2	0.15	0.05	0.48	-	65
ZB-27	1 (z-2)	1.10	0.3	0.15	0.05	0.52	-	65
ZB-28	1 (z-3)	1.10	0.1	0.15	0.05	0.44	-	65
ZB-29	1 (z-3)	1.10	0.2	0.15	0.05	0.48	-	65
ZB-30	1 (z-3)	1.10	0.3	0.15	0.05	0.52	-	65

Table 2. Con't

Specimen	Zeolite (Type*)	Zeolite Aggregate	Portland Cement	Quick Lime	Plaster of Paris	Water	Air En-training Agent	Curing Temp (°C)
ZB-31	1 (z-1)	1.65	0.1	0.15	0.05	0.44	-	65
ZB-32	1 (z-1)	2.20	0.1	0.15	0.05	0.44	-	65
ZB-33	1 (z-1)	1.10	0.1	0.15	0.03	0.44	-	65
ZB-34	1 (z-1)	1.10	0.1	0.15	0.08	0.44	-	65
ZB-35	1 (z-1)	1.10	0.1	0.15	0.05	0.44	-	80-85
ZB-36	1 (z-1)	1.10	0.1	0.15	0.05	0.39	5	85
ZB-37	1 (z-1)	1.10	0.1	0.15	0.05	0.34	10	85
ZB-38	1 (z-9)	1.10	0.1	0.15	0.05	0.77	-	85
ZB-39	1 (z-9)	1.10	0.2	0.15	0.05	0.84	-	85
ZB-40	1 (z-9)	1.10	0.3	0.15	0.05	0.91	-	85
ZB-41	1 (z-10)	1.10	0.1	0.15	0.05	0.77	-	85
ZB-42	1 (z-10)	1.10	0.2	0.15	0.05	0.84	-	85
ZB-43	1 (z-10)	1.10	0.3	0.15	0.05	0.91	-	85
ZB-44	1 (z-1)	1.10	0.1	0.15	0.05	0.41	3	85
ZB-45	1 (z-1)	1.10	0.2	0.15	0.05	0.45	3	85
ZB-46	1 (z-4)	1.10	0.1	0.15	0.05	0.44	-	85
ZB-47	1 (z-4)	1.10	0.2	0.15	0.05	0.48	-	85
ZB-48	1 (z-4)	1.10	0.3	0.15	0.05	0.52	-	85
ZB-49	1 (z-5)	1.10	0.1	0.15	0.05	0.44	-	85
ZB-50	1 (z-5)	1.10	0.2	0.15	0.05	0.48	-	85
ZB-51	1 (z-5)	1.10	0.3	0.15	0.05	0.52	-	85
ZB-52	1 (z-6)	1.10	0.1	0.15	0.05	0.44	-	85
ZB-53	1 (z-6)	1.10	0.2	0.15	0.05	0.48	-	85
ZB-54	1 (z-6)	1.10	0.3	0.15	0.05	0.52	-	85
ZB-55	1 (z-7)	1.10	0.1	0.15	0.05	0.44	-	85
ZB-56	1 (z-7)	1.10	0.2	0.15	0.05	0.48	-	85
ZB-57	1 (z-7)	1.10	0.3	0.15	0.05	0.52	-	85
ZB-58	1 (z-8)	1.10	0.1	0.15	0.05	0.44	-	85
ZB-59	1 (z-8)	1.10	0.3	0.15	0.05	0.52	-	85

Table 3. Mix Design of Zeolite-Based Blocks for Measurement of Drying Shrinkage (Mass Units)

Specimen	Zeolite (Type*)	Zeolite Aggregate	Portland Cement	Quick Lime	Plaster of Paris	Water	Air En-training Agent	Curing Temp (°C)
DS-1	1 (z-1)	1.10	0.1	0.15	0.05	0.44	-	65
DS-2	1 (z-1)	1.20	0.2	0.15	0.05	0.48	-	65
DS-3	1 (z-1)	1.30	0.3	0.15	0.05	0.52	-	65
DS-4	1 (z-2)	1.10	0.1	0.15	0.05	0.44	-	65
DS-5	1 (z-2)	1.10	0.2	0.15	0.05	0.48	-	65
DS-6	1 (z-2)	1.10	0.3	0.15	0.05	0.52	-	65
DS-7	1 (z-3)	1.10	0.1	0.15	0.05	0.44	-	65
DS-8	1 (z-3)	1.10	0.2	0.15	0.05	0.48	-	65
DS-9	1 (z-3)	1.10	0.3	0.15	0.05	0.52	-	65
DS-10	1 (z-1)	1.65	0.1	0.15	0.05	0.44	-	65
DS-11	1 (z-1)	2.20	0.1	0.15	0.05	0.44	-	65
DS-12	1 (z-1)	1.10	0.1	0.15	0.03	0.44	-	65
DS-13	1 (z-1)	1.10	0.1	0.15	0.08	0.44	-	65

§ 2.3. Test Methods

§ 2.3.1. Compressive strength and dry density

Compressive strength and dry density of zeolite-based concretes were determined. Specimens were prepared using the following procedures:

(1) The solids were dry-mixed in a Hobart mixer for 3 minutes;

(2) The water was added gradually during the mixing. The wet sample was mixed for 3 minutes.

(3) Specimens were cast in brass molds (50.8x50.8x50.8 mm). The material was vibrated for about 30 seconds.

(4) Specimens were kept in the laboratory for 60 minutes.

(5) Specimens and molds were placed in a high temperature moist cabinet. The cabinet was temperature controlled from room temperature up to 65 or 85 °C. The temperatures of the concretes were recorded. The cabinet had a relative humidity of 100% at the saturation pressure corresponding to the curing temperature. The specimens were high-temperature cured at 65 or 85 °C for 16 hours if not specified in following discussion.

(6) The concrete specimens were cooled to room temperature in about 4 hours in the curing cabinet. The specimens were then placed in tap water for about 3 hours after demolding. The 1-day compressive strength was determined at about 24 hours after

mixing. The companion specimens were then stored at 23 °C and 50% R.H. for 27 days, before the 28-day strength was determined. The dry density was measured after drying at 105 °C for 7 days.

§ 2.3.2. Drying Shrinkage

The preparation procedures of the specimens for measurement of drying shrinkage was generally the same as those for the strength measurement. The specimen size was 25x25x160 mm. The specimen molds were in accordance with the requirements of ASTM Specification C 490. The specimens were demolded after high-temperature curing and then placed in a plastic container at 23 °C and 100% R.H. The initial length of the specimens was recorded at 24 hours after mixing. The specimens were then stored in room at 23 °C and 50% R.H. for drying. Length change (drying shrinkage) of the specimens was measured at designated ages until 28 days.

§ 2.3.3. Water Absorption

The water absorption capacity of the concretes was determined on the specimens prepared by the same procedures as those for strength test. The water absorption test was carried out on the specimens after room-storage for 27 days at 23 °C and 50% R.H. The specimens were weighed at 28 days and then placed on a water saturated sand-bed in a covered plastic container. A height of 0.5-1 mm from the bottom of the specimens was in direct contact with water. The mass of specimens after absorbing water was measured after 1 days. The water absorption of the concretes was estimated by:

$$\text{Water Absorption} = \frac{M_{wet} - M_{dry}}{M_{dry}} \times 100\%$$

where M_{dry} and M_{wet} are dry mass and wet mass after water-adsorbing of the concretes.

§ 3. Test Results

This test program included 59 different mixes made with 10 different zeolites or volcanic rocks. Four formulation parameters, i.e. the content of portland cement, plaster, aggregate and air entraining agent, were investigated. Two curing conditions, i.e. temperature and period, were studied. The research focused on four important properties of the zeolite concretes, i.e. compressive strength, dry density, water absorption and drying shrinkage. The compressive strength and dry density test results corresponding to 59 different mixes are provided in Table 4. Drying shrinkage data for mixes 1 to 13 is provided in Table 5. Analysis of all data is facilitated by the graphs presented in Figs. 1-33 and Tables 6 - 12.

Table 4. Compressive Strength and Dry Density

Specimens	Compressive Strength (MPa)		Dry Density (kg/m^3)
	After High Temperature Curing (24 hrs)	Following by 27-day Curing at 50% R.H.	
ZB-1	13.5	28.5	1958
ZB-2	14.0	28.6	1957
ZB-3	14.2	28.6	1957
ZB-4	16.5	23.0	2024
ZB-5	17.2	23.2	2028
ZB-6	17.8	23.6	2031
ZB-7	13.9	25.5	2024
ZB-8	15.5	29.9	2030
ZB-9	17.5	30.8	2032
ZB-10	15.1	27.5	2084
ZB-11	18.2	25.5	2124
ZB-12	18.8	27.0	2059
ZB-13	19.8	29.8	2100
ZB-14	14.7	25.1	2078
ZB-15	14.3	27.3	2207
ZB-16	13.5	25.5	2033
ZB-17	17.7	31.5	2020
ZB-18	16.1	22.5	2028
ZB-19	28.7	49.2	1978
ZB-20	13.1	21.7	2027
ZB-21	14.0	28.0	1989
ZB-22	13.4	28.9	1980
ZB-23	14.4	30.4	1953
ZB-24	15.8	34.1	1984
ZB-25	15.5	23.1	1983
ZB-26	16.3	24.0	1995
ZB-27	18.2	24.2	2020
ZB-28	13.3	25.8	1979
ZB-29	14.0	26.7	1981
ZB-30	15.8	29.2	2025

Table 4. Con't

Specimen	Compressive Strength (MPa)		Dry Density (kg/m^3)
	After High Temperature Curing (16 hours)	Following by 27-Day Curing at 50% R.H.	
ZB-31	14.5	29.8	2068
ZB-32	15.1	30.0	2088
ZB-33	12.1	19.4	1967
ZB-34	14.5	29.9	1982
ZB-35	18.1	24.6	1988
ZB-36	4.0	5.3	1418
ZB-37	3.0	5.0	1380
ZB-38	10.1	12.0	1312
ZB-39	12.7	12.9	1313
ZB-40	14.4	13.6	1315
ZB-41	10.4	11.5	1331
ZB-42	14.2	15.0	1360
ZB-43	18.6	18.9	1361
ZB-44	6.5	9.5	1640
ZB-45	6.7	9.7	1699
ZB-46	18.7	25.5	1909
ZB-47	18.9	26.1	1931
ZB-48	19.1	29.4	1940
ZB-49	20.3	30.6	1921
ZB-50	-	-	-
ZB-51	21.7	34.4	1950
ZB-52	16.7	20.5	1850
ZB-53	20.5	26.7	1847
ZB-54	26.7	34.6	1871
ZB-55	13.0	22.9	1913
ZB-56	14.3	23.9	1988
ZB-57	15.3	24.5	1993
ZB-58	22.9	25.5	1818
ZB-59	26.5	30.3	1822

Table 5. Drying Shrinkage of Zeolite-Based Blocks (%)

	Drying at 50% R.H. for		
	7 days	14 days	28 days
DS-1	0.090	0.118	0.124
DS-2	0.072	0.112	0.118
DS-3	0.062	0.096	0.110
DS-4	0.084	0.118	0.122
DS-5	0.084	0.144	0.174
DS-6	0.074	0.134	0.148
DS-7	0.110	0.144	0.154
DS-8	0.110	0.140	0.150
DS-9	0.090	0.114	0.130
DS-10	0.084	0.112	0.114
DS-11	0.074	0.096	0.096
DS-12	0.110	0.140	0.148
DS-13	0.096	0.118	0.124

§ 3.1. Compressive Strength

§ 3.1.1. Effect of Portland Cement Content

The effect of portland cement content on the compressive strength of concretes made with z-1 is shown in Fig. 1. The compressive strength of the concretes slightly increased with the increase of cement content at both 1 day and 28 days. The 1-day strength was tested just after high temperature curing and the 28-day strength was tested after another 27 days storage at 23 °C and about 50% R.H. The 28 day strength (about 28 MPa) doubled the 1 day strength which is sufficient for load-bearing concrete products.

The effect of portland cement content on the compressive strength of concretes made with z-2 is shown in Fig. 2. The compressive strength of the concretes also slightly increased with the increase of cement content at 1 day and 28 days. The 1-day strength of z-2 concretes was higher than that of z-1 concretes. However, the 28-day strength of the z-2 concretes was lower than that of z-1 concretes.

The effect of portland cement content on the compressive strength of concretes made with z-3 is shown in Fig. 3. The compressive strength of the concretes increased with the increase of cement content at both 1 day and 28 days. The effect of cement content on z-3 concretes was more significant than on the z-1 and z-2 concretes. The 28-day strength of z-3 concretes reached 30 MPa.

The effect of portland cement content on the compressive strength of concretes made with z-4 is shown in Fig. 4. The z-4 was the remaining volcanics of z-1 zeolite rocks after the zeolites has been extracted by magnetic separation. The compressive strength of the concretes slightly increased with the increase of cement content at both 1 day and 28 days. The 1-day strength is increased to 19 MPa.

The effect of portland cement content on the compressive strength of concretes made with z-5 is shown in Fig. 5. The z-5 was the remaining volcanics of z-1 zeolite rocks after zeolite has been extracted after 2 applications of the separation process. magnetic fraction. The compressive strength of the concretes increased with the increase of cement content at both 1 day and 28 days. The 1-day strengths of the z-5 concretes were about the same as those of the z-1 concretes, but lower than those of z-4 concretes. The 28-day strength of z-5 concretes were lower than those of the z-1 and z-4 concretes.

The effect of portland cement content on the compressive strength of concretes made with z-6 is shown in Fig. 6. The z-6 was pure zeolite extracted from z-2. The compressive strength of the concretes clearly increased with the increase of cement content at both 1 day and 28 days. The concrete containing 30% cement by mass of zeolite had 1-day and 28-day strengths of about 26 and 34 MPa respectively.

The effect of portland cement content on the compressive strength of concretes made with z-7 is shown in Fig. 7. The z-7 was pure zeolite (stilbite) extracted from z-3. The compressive strength of the concretes increased with the increase of cement content at both 1 day and 28 days. The 1-day strengths of the z-7 concretes were higher than those of the z-3 concretes.

The effect of portland cement content on the compressive strength of concretes made with z-8 is shown in Fig. 8. The z-8 was the remaining volcanics of z-3 zeolite rock after the zeolite has been extracted by magnetic fractionation. The compressive strength of the concretes increased slightly with the increase of cement content at both 1 day and 28 days. The 1-day and 28-day strengths were about 20 and 30 MPa respectively, higher than those of z-3 concrete.

The effect of portland cement content on the compressive strength of concretes made with z-9 is shown in Fig. 9. The z-9 material is lightweight and has a high surface area. Therefore it requires more water to satisfy the workability. The water/zeolite ratio for z-9 concretes was higher than 0.7, while that for the z-1 to z-8 concretes was less than 0.52. The compressive strength of the concretes clearly increased with the increase of cement content at both 1 day and 28 days. The strength developed mostly during high temperature curing. The 1-day and 28-day strengths of the z-9 concretes were almost the same. They were lower than those of z-1 to z-8 concretes.

The effect of portland cement content on the compressive strength of concretes made with z-10 is shown in Fig. 10. The physical characteristics of z-10 is similar to those of z-9. The compressive strength of the concretes increased with the increase of cement content at both 1 day and 28 days. The 1-day and 28-day strengths of the z-10 concretes were lower than those of the z-1 to z-8 concretes. Little strength developed after high temperature curing.

§ 3.1.2. Effect of Aggregate Content

The effect of aggregate content on the compressive strength of concretes made with z-1 is shown in Fig. 11. The aggregate was prepared by crushing z-1 rocks. The strength increased with the increase of aggregate content from agg./zeolite ratio 1.10 to 1.65 and then decreased with the further increase of aggregate content to an agg./zeolite ratio 2.20.

The effect of aggregate content on the compressive strength of concretes made with z-2 is shown in Fig. 12. The aggregate was prepared by crushing z-2 rocks. The strength slightly increased with the increase of aggregate content.

The effect of aggregate content on the compressive strength of concretes made with z-3 is shown in Fig. 13. The aggregate was prepared by crushing z-3 rocks. Little effect of the aggregate on strength was found in z-3 concretes.

§ 3.1.3. Effect of Plaster of Paris Content

The effect of plaster content on the compressive strength of concretes made with z-1 is shown in Fig. 14. The compressive strength of the concretes slightly increased with the increase of plaster content at both 1 day and 28 days.

The effect of plaster content on the compressive strength of concretes made with z-2 is shown in Fig. 15. Little difference in compressive strength was found with the increase of plaster content at 1 day and 28 days.

The effect of plaster content on the compressive strength of concretes made with z-3 is shown in Fig. 16. The compressive strength of the concretes slightly increased with the increase of plaster content at both 1 day and 28 days.

§ 3.1.4. Effect of Curing Temperature

The compressive strengths of concretes (made with z-1) cured at 65 °C and 85 °C are shown in Figs. 17 and 1 respectively.

The compressive strengths of concretes (made with z-2) cured at 65 °C and 85 °C are shown in Figs. 18 and 2 respectively.

The compressive strengths of concretes (made with z-3) cured at 65 °C and 85 °C are shown in Figs. 19 and 3 respectively.

The compressive strengths of concretes (made with z-1 and different aggregate contents) cured at 65 °C and 85 °C are shown in Figs. 20 and 11 respectively.

The compressive strengths of concretes (made with z-1 and different plaster contents) cured at 65 °C and 85 °C are shown in Figs. 21 and 14 respectively.

The 1-day and 28-day compressive strengths of concretes initially cured at 65 °C were similar to those cured at 85 °C from the comparison of above results. Therefore 65 °C moist-curing is the most practical temperature to obtain maximum strength for the concretes.

§ 3.1.5. Effect of High Temperature Curing Period

The compressive strengths of concretes (made with z-1 volcanic rocks) cured at 85 °C for 5, 9 and 16 hours are shown in Fig. 22. About 75% of the 16 hour strength was obtained in the first 5 hours. The 1-day strength increased about 23% and 3% from 5 hours to 9 hours and from 9 hours to 16 hours, respectively. The 28-day strength of concretes cured for different periods were almost the same.

§ 3.1.6. Effect of an Air Entraining Agent

The effect of the addition of an air entraining agent on compressive strength of z-1 concretes is shown in Fig. 23. The compressive strength significantly decreased with the addition of an air entraining agent. The 1-day and 28-day strength of the z-1 concretes containing 3% air entraining agent were about 6 and 9 MPa respectively.

§ 3.2. Dry Bulk Density

§ 3.2.1. Effect of Portland Cement Content

The effect of portland cement content on dry bulk density of zeolite concretes made with different zeolite rocks is provided in Tables 6 to 8. In general, the dry density values of zeolite concretes made with Nova Scotia rocks (z-1 to z-8) were about 2000 kg/m^3. They are lower than conventional portland cement concretes (about 2400 kg/m^3), and higher than pure zeolite concretes (less than 1400 kg/m^3, e.g. z-9 and z-10). Concretes made with pure zeolites extracted from Nova Scotia rocks (z-6 and z-7) are about 1800-1900 kg/m^3 and are lower than those directly made with the rocks. The dry density of concretes slightly increased with the increase of cement content.

Table 6. Effect of Cement Content on Dry Density of Concretes Made with z-1, z-2 or z-3 (kg/m^3)

Cement Content (mass% of zeolite)	Type of Zeolite			Specimen Designation
	z-1	z-2	z-3	
10	1958	2024	2024	ZB-1; ZB-4; Z-B-7
20	1957	2028	2030	ZB-2; ZB-5; ZB-8
30	1957	2031	2032	ZB-3; ZB-6; ZB-9

Note: The zeolite-based concretes were initially cured at 85 °C for 16 hours in the first twenty four hours and than dried at 105 °C for 7 days.

Table 7. Effect of Cement Content on Dry Density of Concretes Made with z-4, z-5, z-6, z-7 and z-8 (kg/m^3).

Cement Content (mass% of zeolite)	Type of Zeolite					Specimen Designation
	z-4	z-5	z-6	z-7	z-8	
10	1909	1913	1850	1818	1921	ZB-46; ZB-55; ZB-52; ZB-58; ZB-49
20	1931	1988	1847	-	-	ZB-47; ZB-56; ZB-53; - ZB-50
30	1940	1993	1871	1822	1950	ZB-48; ZB-57; ZB-54; ZB-59; ZB-51

Note: The zeolite-based concretes were initially cured at 85 °C for 16 in the first twenty four hours and than dried at 105 °C for 7 days.

Table 8. Effect of Cement Content on Dry Density of Concretes Made with z-9 or z-10 (kg/m^3).

Cement Content (mass% of zeolite)	Type of Zeolite		Specimen Designation
	z-9	z-10	
10	1312	1331	ZB-38; ZB-41;
20	1313	1360	ZB-39; ZB-42;
30	1315	1361	ZB-40; ZB-43;

Note: The zeolite-based concretes were initially cured at 85 °C for 16 hours in the first twenty four hours and than dried at 105 °C for 7 days.

§ 3.2.2. Effect of Aggregate Content

The effect of aggregate (crushed rock) content on dry bulk density of zeolite concretes made with different zeolite rocks is provided in Table 9. The dry bulk density increased with the increase of aggregate content in the concretes.

Table 9. Effect of Aggregate Content on Dry Density of Concretes Made with z-1, z-2 or z-3 (kg/m³).

Agg. / Zeolite	Type of Zeolite			Specimen Designation
	z-1	z-2	z-3	
1.10	1958	2024	2024	ZB-1; ZB-4; ZB-7
1.65	2032	2059	2078	ZB-10; ZB-12; ZB-14
2.20	2084	2100	2207	ZB-11; ZB-13; ZB-15

Note: The zeolite-based concretes were initially cured at 85 °C for 16 hours in the first twenty four hours and than dried at 105 °C for 7 days.

§ 3.2.3. Effect of Plaster of Paris

The effect of Plaster content on dry bulk density of zeolite concretes made with different zeolite rocks is provided in Table 10. The dry bulk density decreased with the increase of plaster content in the concretes.

Table 10. Effect of Content of Plaster of Paris on Dry Density of Concretes Made with z-1, z-2 or z-3 (kg/m³).

Plaster of Paris	Type of Zeolite			Specimen Designation
(mass% of zeolite)	z-1	z-2	z-3	
3	2033	2028	2027	ZB-16; ZB-18; ZB-20
5	2032	2024	2024	ZB-1; ZB-4; ZB-7
8	2020	1978	1989	ZB-17; ZB-19; ZB-21

Note: The zeolite-based concretes were initially cured at 85 °C for 16 hours in the first twenty four hours and than dried at 105 °C for 7 days.

§ 3.2.4. Effect of an Air Entraining Agent

The effect of addition of an air entraining agent on dry bulk density of zeolite concretes made with different zeolite rocks is provided in Table 11. The dry bulk density decreased significantly with the addition of an air entraining agent.

Table 11. Effect of an Air Entraining Agent on Dry Density of Concretes Made with z-1 (kg/m^3).

Air Entraining (mass% of zeolite)	Dry Density	Specimen Designation
0	1958	ZB-1
3	1640	ZB-44
5	1418	ZB-36
10	1380	ZB-37

Note: The zeolite-based concretes were initially cured at 85 °C for 16 hours and than dried at 105 °C for 7 days.

§ 3.3. Drying Shrinkage

§ 3.3.1. Effect of Portland Cement Content

The effect of portland cement content on drying shrinkage of concretes stored at 23 °C and 50% R.H. is shown in Figs. 24 to 26. The concrete specimens were made with z-1, z-2 or z-3 zeolite rocks and initially cured at 85 °C. The drying shrinkage generally decreased with the increase of cement content probably due to the shrinkage of zeolite hydrates larger than cement hydrates. The drying shrinkage occurred mainly in the first two weeks. The z-1 concretes exhibited less drying shrinkage than the z-2 and z-3 concretes. Its drying shrinkage at 28 days was about 0.12%. The z-2 concrete containing 10% cement showed a high drying shrinkage which was larger than 0.17% at 28 days. Its drying shrinkage reduced to about 0.12% when cement content increased to 30%. The drying shrinkage value of z-3 concrete were between that of z-1 and z-2 concretes.

§ 3.3.2. Effect of Aggregate Content

The effect of aggregate content on drying shrinkage of concretes stored at 23 °C and 50% R.H. is shown in Fig. 27. The concrete specimens were made with z-1 zeolite rocks and initially cured at 85 °C. The drying shrinkage decreased with the increase of aggregate content. The drying shrinkage reduced from 0.12% to 0.10% when the aggregate/zeolite ratio doubled from 1.10 to 2.20. The drying shrinkage took place mainly in the first two weeks.

§ 3.3.3. Effect of Plaster of Paris Content

The effect of plaster content on drying shrinkage of concretes stored at 23 °C and 50% R.H. is shown in Fig. 28. The concrete specimens were made with z-1 zeolite rocks and initially cured at 85 °C. The drying shrinkage decreased with the increase of plaster content. A large decrease of drying shrinkage occurred when the plaster content increased from 3% to 5%. The further increase of plaster content to 8% did not show any improvement after 14 days. The drying shrinkage occurred mainly in the first two weeks.

§ 3.3.4. Effect of Storage Time after High Temperature Curing

The effect of storage time on the effective drying shrinkage of concretes is shown in Table 12. Specimens DS-1 to 13 were made with z-1, z-2 or z-3 zeolite rocks and various contents of cement, aggregate and plaster (see Table 2, Mix Design). The 28-day drying shrinkage were used as ultimate values in this calculation of effective drying shrinkage. It is assumed that the further drying shrinkage after 28 days were very small. The effective drying shrinkage is:

$$DS_{Effective} = DS_{Ultimate} - DS_{Initial}$$

where $DS_{Effective}$ is the effective drying shrinkage after purchase of the products; $DS_{Initial}$ is the initial drying shrinkage occurring during the storage period before purchase; $DS_{Ultimate}$,is the ultimate drying shrinkage.

The Table 12 indicated that the effective drying shrinkage in actual use after purchase can be significantly reduced by increasing the storage time up to two weeks since the drying shrinkage mainly takes place in the first two weeks. The effective drying shrinkage after two-week storage is mostly less than 0.01% which is accepted by both US and Canada standards. This storage time is also referred to as stabilization period of concrete production. It is conventionally applied in the concrete concrete manufacture.

§ 3.4. Water Absorption

§ 3.4.1. Effect of Portland Cement Content

The effect of portland cement content on water absorption by concretes made with z-1 and z-3 is shown in Fig. 29. The concrete specimens were initially cured at 85 °C. The water adsorption slightly decreased with the increase of cement content in the concretes. The z-1 and z-3 concretes showed similar capacity of water absorption.

The effect of portland cement content on water absorption by concretes made with z-9 and z-10 is shown in Fig. 30. The concrete specimens were initially cured at 85 °C. The water absorption significantly decreased with the increase of cement content in the concretes. The z-9 and z-10 concretes showed similar capacity of water absorption. They had much higher water absorption values than those of z-1 and z-3 concretes. The z-9 and z-10 are pure zeolite. The z-1 and z-3 zeolites contain large amount of volcanic rocks.

Table 12. Effective Drying Shrinkage (DS) after Different Storage Time at 50% R.H.

	Storage Time after High Temperature Curing		
	< 1 day	1 week	2 weeks
DS-1	0.12	0.03	< 0.01
DS-2	0.12	0.05	< 0.01
DS-3	0.11	0.05	0.01
DS-4	0.12	0.04	< 0.01
DS-5	0.17	0.09	0.03
DS-6	0.15	0.07	0.01
DS-7	0.15	0.04	0.01
DS-8	0.15	0.04	0.01
DS-9	0.13	0.04	0.02
DS-10	0.11	0.03	< 0.01
DS-11	0.10	0.02	< 0.01
DS-12	0.15	0.04	< 0.01
DS-13	0.12	0.03	< 0.01

§ 3.4.2. Effect of Aggregate Content

The effect of aggregate content on water absorption by concretes made with z-1 is shown in Fig. 31. The concrete specimens were initially cured at 85 °C. The water absorption greatly increased with the increase of aggregate content in the concretes.

§ 3.4.3. Effect of Plaster of Paris Content

The effect of plaster content on water absorption by concretes made with z-1 is shown in Fig. 32. The concrete specimens were initially cured at 85 °C. The water absorption slightly decreased with the increase of plaster content in the concretes.

§ 3.4.4. Effect of Air Entraining Agent

The effect of addition of air entraining agent on water absorption by concretes made with z-1 zeolite rocks is shown in Fig. 33. The concrete specimens were initially cured at 85 °C. The water absorption increased with the addition of air entraining agent in the concretes, especially when the content increased from 5% to 10%.

§ 4. Conclusions

1. The Nova Scotia zeolite rocks (z-1 to z-8) can be used as supplementary cementitious materials and aggregates in the production of high temperature cured zeolite-based concrete products.

2. The US zeolites (z-9 and z-10) can be used as supplementary cementitious materials in production of high temperature cured zeolite-based concrete products.

3. The suggested mix design for the zeolite-based concrete products based on this study is as follows (mass units):

zeolite powder < 0.08 mm	Type 10 portland cement	zeolite aggregate 0.3 mm - 5 mm	plaster of Paris	quick lime	water
1	0.1-0.3	1.1-2.2	0.5	0.15	0.44-0.52

4. It is suggested that the initial curing temperature in the production of zeolite-based concrete products be in the range of 65 to 85 °C.

5. It is suggested that the high temperature curing period for the production of zeolite-based concrete products is in the range of 5 to 9 hours.

6. A storage period (at about 23 °C and 50% R.H.) of a two weeks before use is suggested to minimize the drying shrinkage.

7. The 1-day compressive strength (after high temperature curing) of zeolite-based concrete products made with Nova Scotia zeolite rocks is in the range of 12 to 16 MPa.

8. The 28-day compressive strength (after storage at 23 °C and 50% R.H.) of zeolite-based concrete products made with Nova Scotia zeolite rocks is in the range of 20 to 30 MPa.

9. The dry bulk density of zeolite-based concrete products made with Nova Scotia zeolite rocks is in the range of 1900 to 2100 kg/m^3.

10. The effective drying shrinkage (Nova Scotia material) after 1-week storage at 23 °C and 50% R.H. is in the range of 0.02 to 0.05%. The effective drying shrinkage after a 2-week storage period is about 0.01%.

11. The 1-day and 28-day compressive strengths of zeolite-based concrete products made with the US zeolites (z-9 and z-10) are all in the range of 10 to 14 MPa.

12. The dry bulk density of zeolite-based concrete products made with the US zeolites is in the range of 1300 to 1400 kg/m^3.

§ 5. Recommendations

Further research is necessary for industrial production of zeolite-based concrete products using Nova Scotia zeolite rocks. This would include the following:

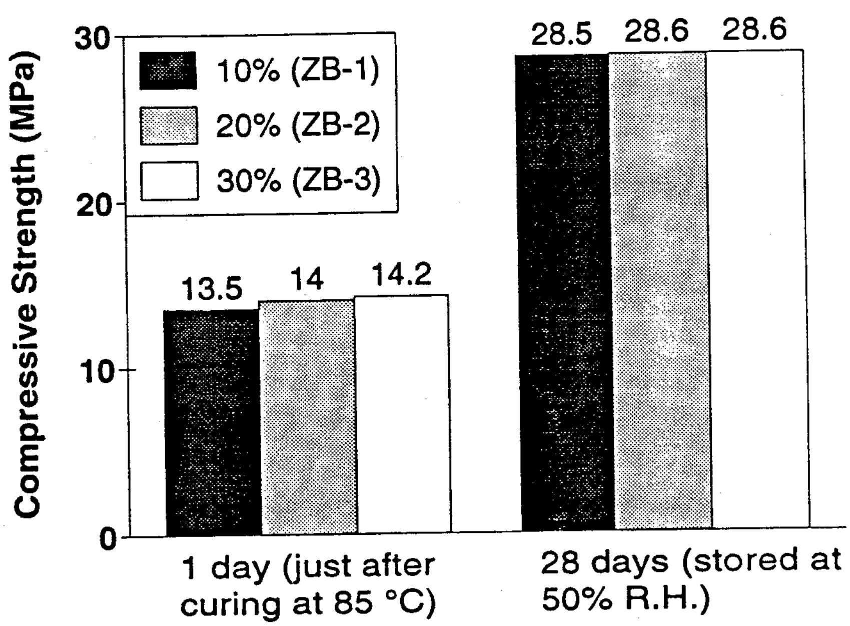
1. An evaluation of air-entraining admixture technology to develop concrete products with a low dry bulk density and acceptable compressive strength.

2. Selection and testing of different chemical admixtures and foam stabilizers to maximize performance.

3. Development/modification of standards and test methods for quality control.

4. Determination of relevant engineering properties such as flexural strength, thermal conductivity, fire resistance and resistance to efflorescence.

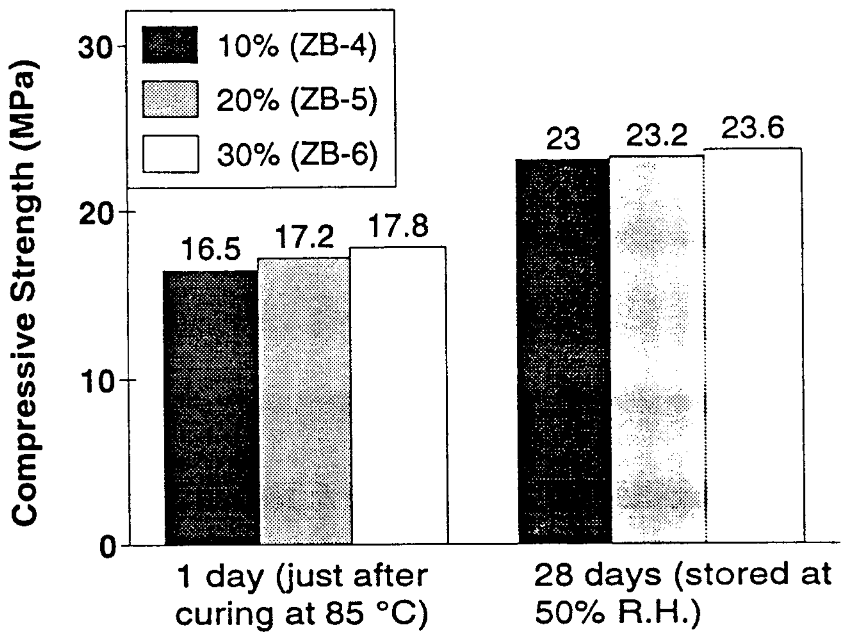
5. Measurement of durability in severe environment e.g., exposure to sulphate, acid and freeze-thaw cycles.



Mixes: mass units

Spcimen	Zeolite (Type*)	Zeolite Aggregate	Portland Cement	Quick Lime	Plaster of Paris	Water	Curing Temp (°C)
ZB-1	1 (z-1)	1.10	0.1	0.15	0.05	0.44	85
ZB-2	1 (z-1)	1.10	0.2	0.15	0.05	0.48	85
ZB-3	1 (z-1)	1.10	0.3	0.15	0.05	0.52	85

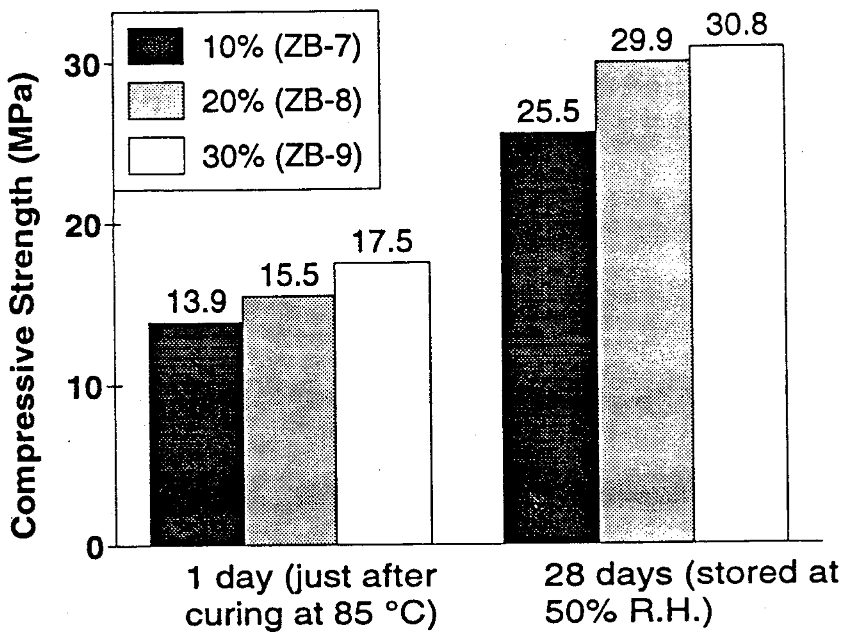
Fig. 1. Effect of cement content on compressive strength of concretes made with z-1 (initially cured at 85 °C and 100% R.H. for 16 hours during the first 24 hours and then stored at 23 °C and 50% R.H.).



Mixes: mass units

Spcimen	Zeolite (Type*)	Zeolite Aggregate	Portland Cement	Quick Lime	Plaster of Paris	Water	Curing Temp (°C)
ZB-4	1 (z-2)	1.10	0.1	0.15	0.05	0.44	85
ZB-5	1 (z-2)	1.10	0.2	0.15	0.05	0.48	85
ZB-6	1 (z-2)	1.10	0.3	0.15	0.05	0.52	85

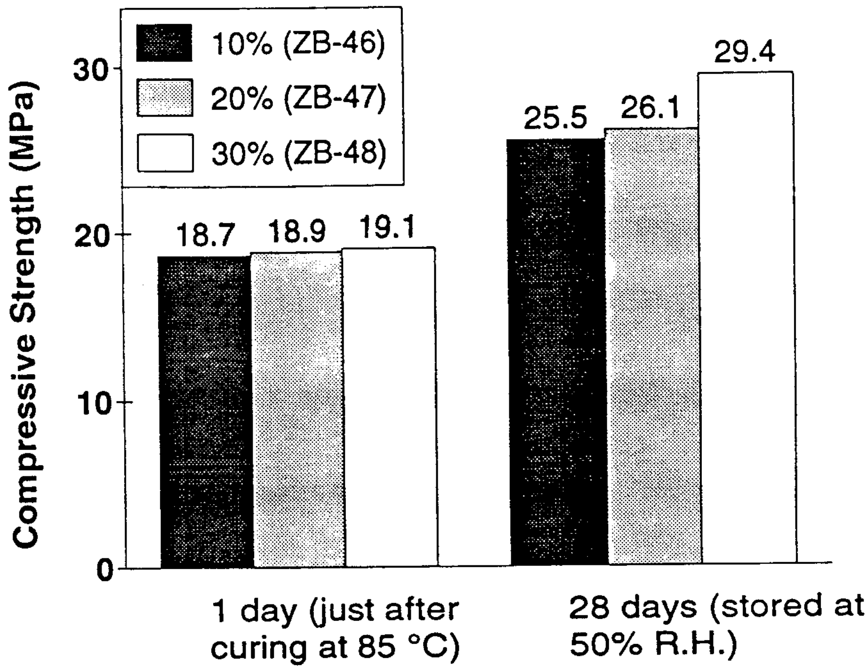
Fig. 2. Effect of cement content on compressive strength of concretes made with z-2 (initially cured at 85 °C and 100% R.H. for 16 hours during the first 24 hours and then stored at 23 °C and 50% R.H.).



Mixes: mass units

Spcimen	Zeolite (Type*)	Zeolite Aggregate	Portland Cement	Quick Lime	Plaster of Paris	Water	Curing Temp (°C)
ZB-7	1 (z-3)	1.10	0.1	0.15	0.05	0.44	85
ZB-8	1 (z-3)	1.10	0.2	0.15	0.05	0.48	85
ZB-9	1 (z-3)	1.10	0.3	0.15	0.05	0.52	85

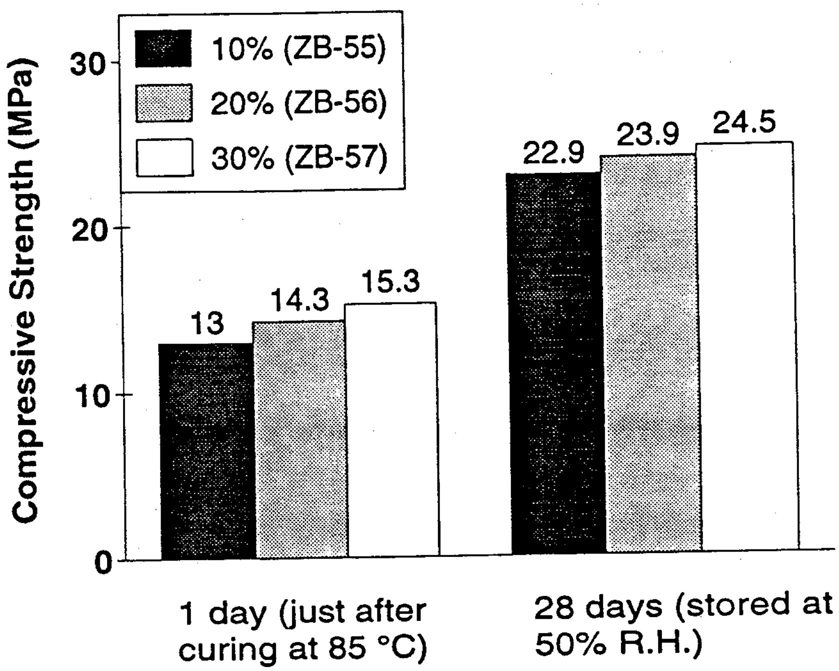
Fig. 3. Effect of cement content on compressive strength of concretes made with z-3 (initially cured at 85 °C and 100% R.H. for 16 hours during the first 24 hours and then stored at 23 °C and 50% R.H.).



Mixes: mass units

Spcimen	Zeolite (Type*)	Zeolite Aggregate	Portland Cement	Quick Lime	Plaster of Paris	Water	Curing Temp (°C)
ZB-46	1 (z-4)	1.10	0.1	0.15	0.05	0.44	85
ZB-47	1 (z-4)	1.10	0.2	0.15	0.05	0.48	85
ZB-48	1 (z-4)	1.10	0.3	0.15	0.05	0.52	85

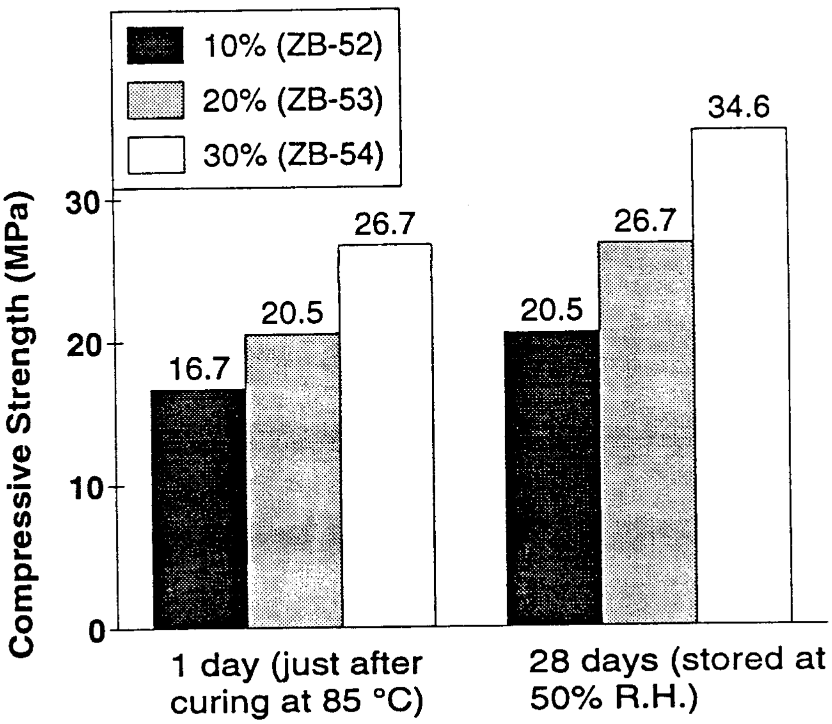
Fig. 4. Effect of cement content on compressive strength of concretes made with z-4 (initially cured at 85 °C and 100% R.H. for 16 hours during the first 24 hours and then stored at 23 °C and 50% R.H.).



Mixes: mass units

Spcimen	Zeolite (Type*)	Zeolite Aggregate	Porland Cement	Quick Lime	Plaster of Paris	Water	Curing Temp (°C)
ZB-55	1 (z-5)	1.10	0.1	0.15	0.05	0.44	85
ZB-56	1 (z-5)	1.10	0.2	0.15	0.05	0.48	85
ZB-57	1 (z-5)	1.10	0.3	0.15	0.05	0.52	85

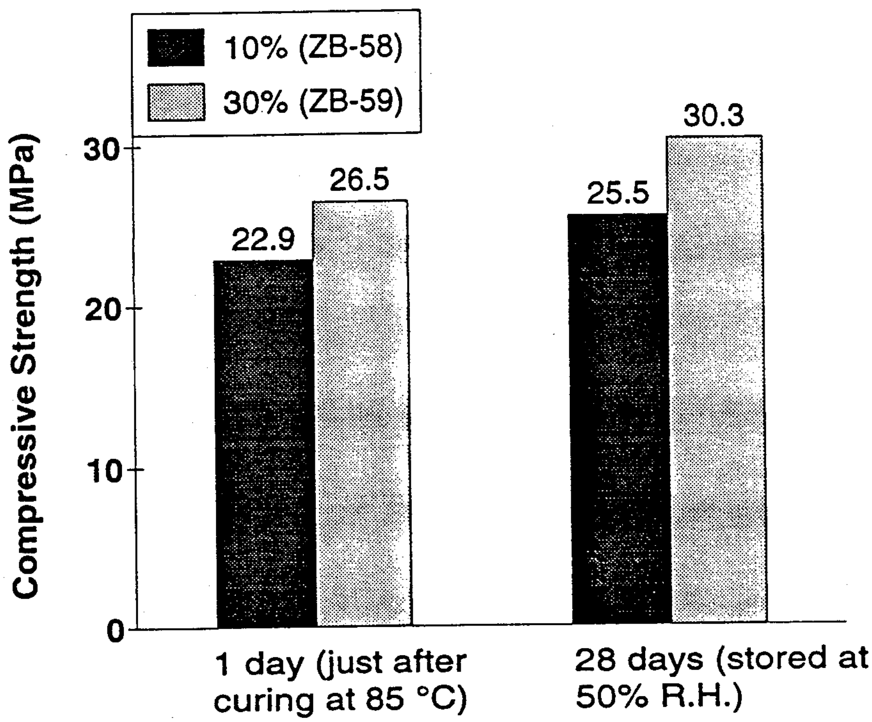
Fig. 5. Effect of cement content on compressive strength of concretes made with z-5 (initially cured at 85 °C and 100% R.H. for 16 hours and then stored at 23 °C and 50% R.H.).



Mixes: mass units

Spcimen	Zeolite (Type*)	Zeolite Aggregate	Portland Cement	Quick Lime	Plaster of Paris	Water	Curing Temp (°C)
ZB-52	1 (z-6)	1.10	0.1	0.15	0.05	0.44	85
ZB-53	1 (z-6)	1.10	0.2	0.15	0.05	0.48	85
ZB-54	1 (z-6)	1.10	0.3	0.15	0.05	0.52	85

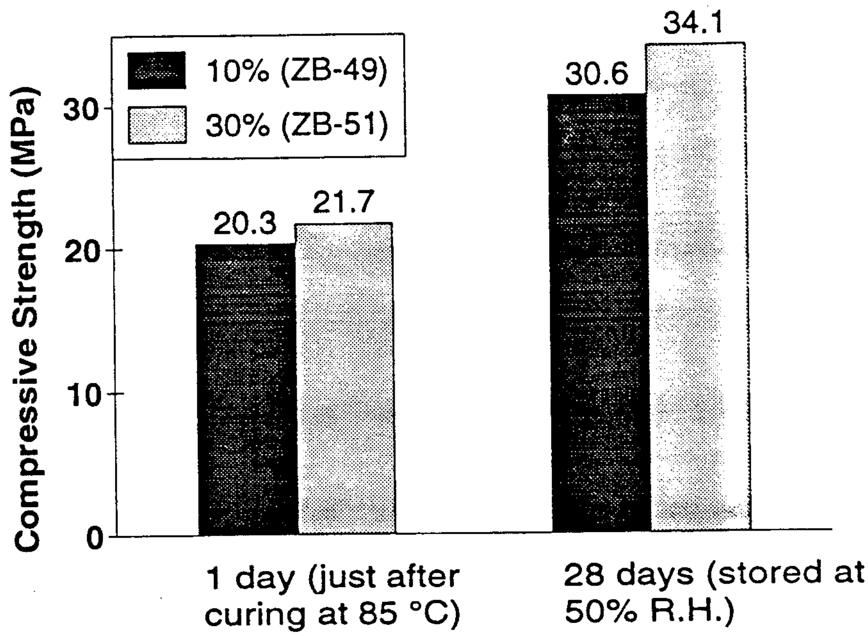
Fig. 6. Effect of cement content on compressive strength of concretes made with z-6 (initially cured at 85 °C and 100% R.H. for 16 hours during the first 24 hours and then stored at 23 °C and 50% R.H.).



Mixes: mass units

Spcimen	Zeolite (Type*)	Zeolite Aggregate	Portland Cement	Quick Lime	Plaster of Paris	Water	Curing Temp (°C)
ZB-58	1 (z-7)	1.10	0.1	0.15	0.05	0.44	85
ZB-59	1 (z-7)	1.10	0.3	0.15	0.05	0.52	85

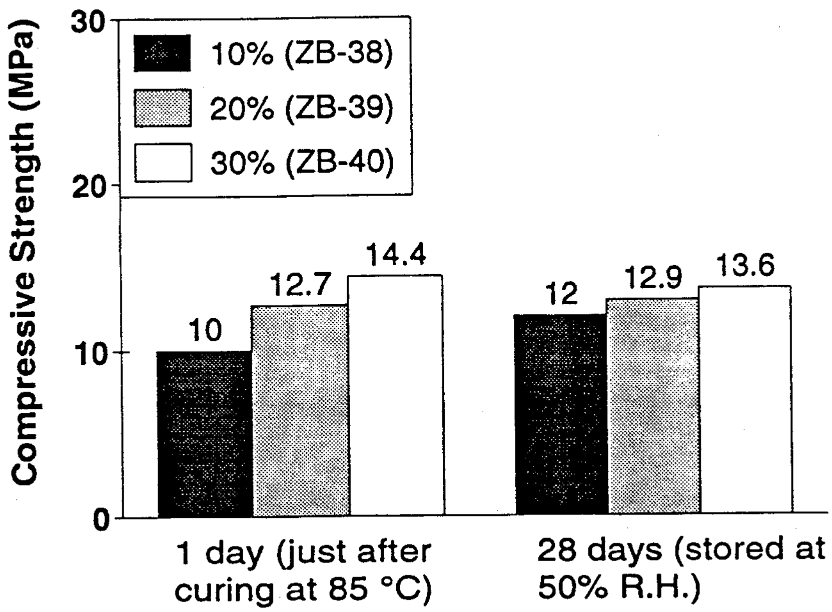
Fig. 7. Effect of cement content on compressive strength of concretes made with z-7 (initially cured at 85 °C and 100% R.H. for 16 hours during the first 24 hours and then stored at 23 °C and 50% R.H.).



Mixes: mass units

Spcimen	Zeolite (Type*)	Zeolite Aggregate	Portland Cement	Quick Lime	Plaster of Paris	Water	Curing Temp (°C)
ZB-49	1 (z-8)	1.10	0.1	0.15	0.05	0.44	85
ZB-50	1 (z-8)	1.10	0.3	0.15	0.05	0.52	85

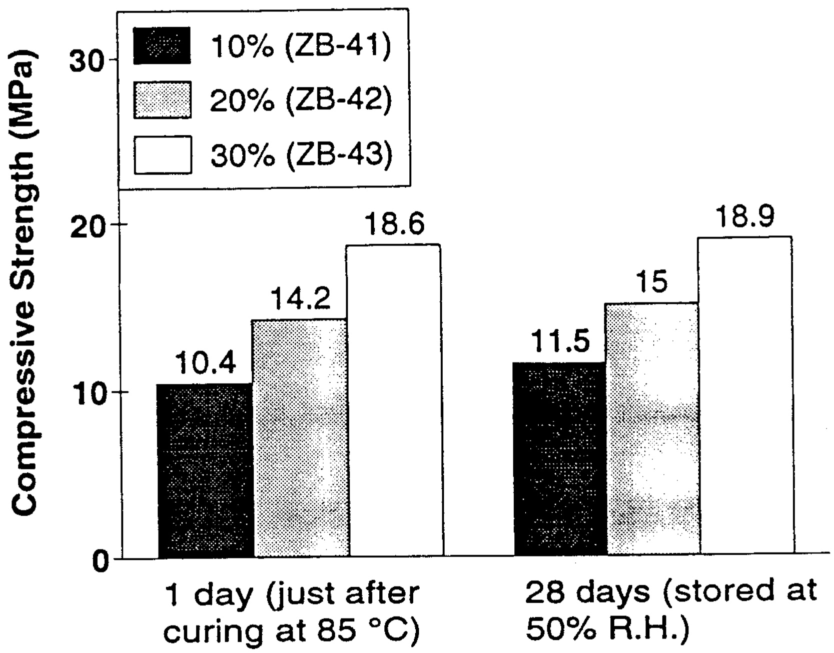
Fig. 8. Effect of cement content on compressive strength of concretes made with z-8 (initially cured at 85 °C and 100% R.H. for 16 hours during the first 24 hours and then stored at 23 °C and 50% R.H.).



Mixes: mass units

Spcimen	Zeolite (Type*)	Zeolite Aggregate	Portland Cement	Quick Lime	Plaster of Paris	Water	Curing Temp (°C)
ZB-38	1 (z-9)	1.10	0.1	0.15	0.05	0.77	85
ZB-39	1 (z-9)	1.10	0.2	0.15	0.05	0.84	85
ZB-40	1 (z-9)	1.10	0.3	0.15	0.05	0.91	85

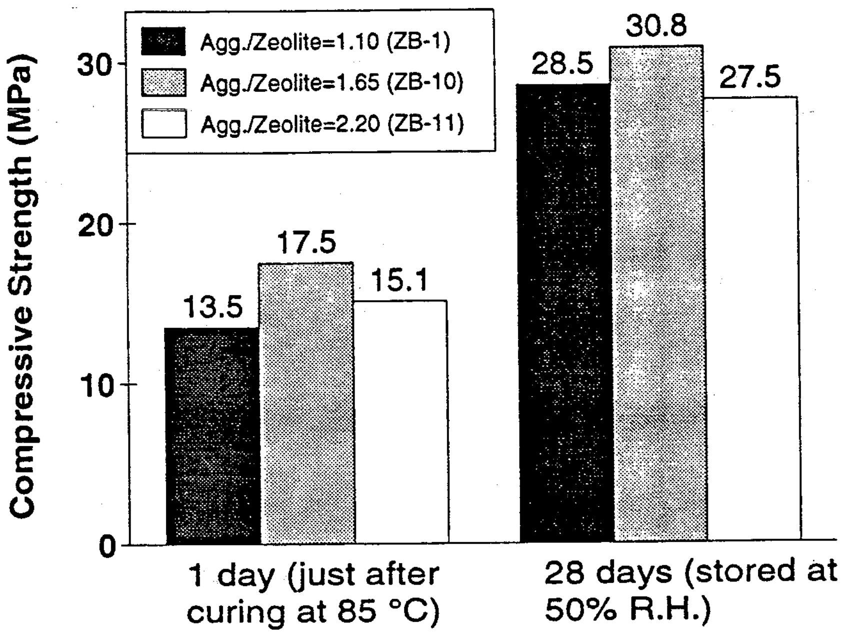
Fig. 9. Effect of cement content on compressive strength of concretes made with z-9 (initially cured at 85 °C and 100% R.H. for 16 hours during the first 24 hours and then stored at 23 °C and 50% R.H.).



Mixes: mass units

Spcimen	Zeolite (Type*)	Zeolite Aggregate	Portland Cement	Quick Lime	Plaster of Paris	Water	Curing Temp (°C)
ZB-41	1 (z-10)	1.10	0.1	0.15	0.05	0.77	85
ZB-42	1 (z-10)	1.10	0.2	0.15	0.05	0.84	85
ZB-43	1 (z-10)	1.10	0.3	0.15	0.05	0.91	85

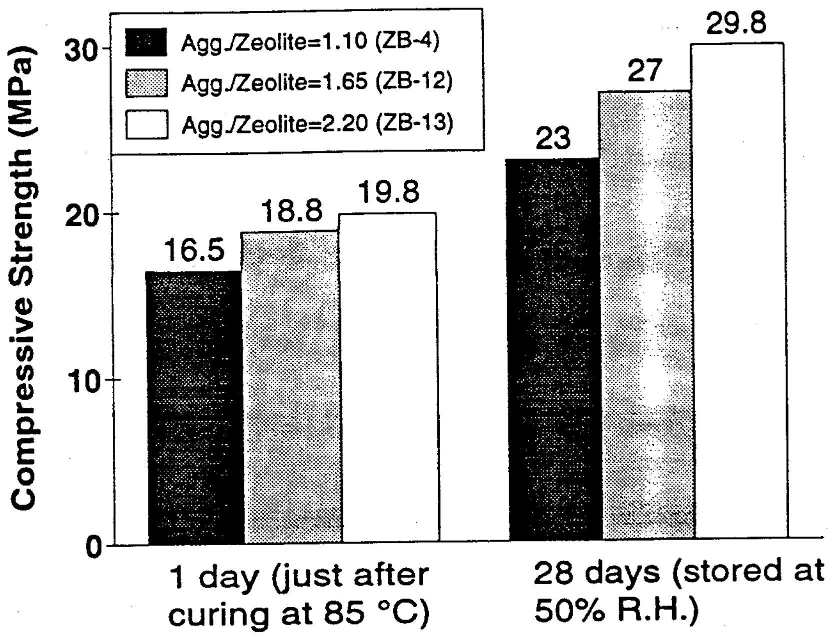
Fig. 10. Effect of cement content on compressive strength of concretes made with z-10 (initially cured at 85 °C and 100% R.H. for 16 hours during the first 24 hours and then stored at 23 °C and 50% R.H.).



Mixes: mass units

Spcimen	Zeolite (Type*)	Zeolite Aggregate	Portand Cement	Quick Lime	Plaster of Paris	Water	Curing Temp (°C)
ZB-1	1 (z-1)	1.10	0.1	0.15	0.05	0.44	85
ZB-10	1 (z-1)	1.65	0.1	0.15	0.05	0.44	85
ZB-11	1 (z-1)	2.20	0.1	0.15	0.05	0.44	85

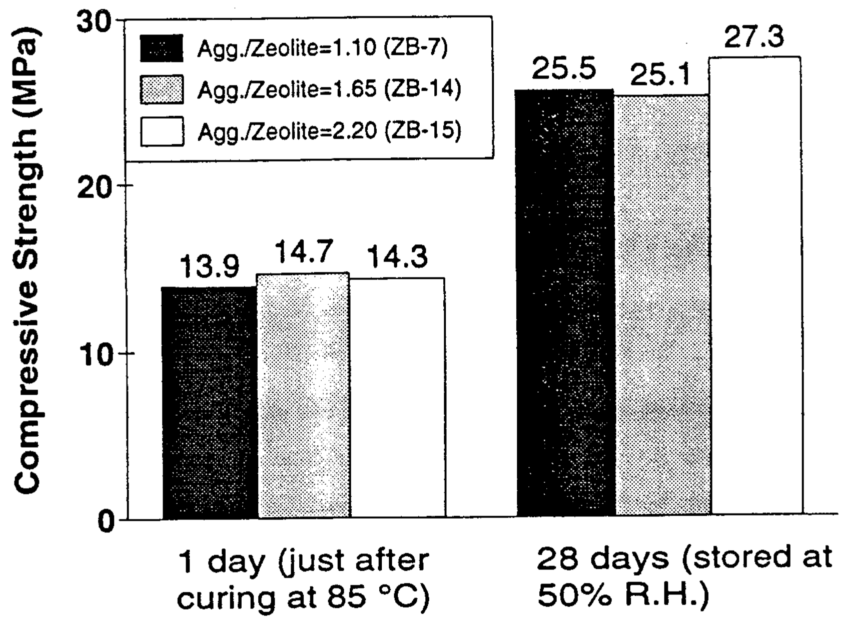
Fig. 11. Effect of aggregate content on compressive strength of concretes made with z-1 (initially cured at 85 °C and 100% R.H. for 16 hours during the first 24 hours and then stored at 23 °C and 50% R.H.).



Mixes: mass units

Spcimen	Zeolite (Type*)	Zeolite Aggregate	Portland Cement	Quick Lime	Plaster of Paris	Water	Curing Temp (°C)
ZB-4	1 (z-2)	1.10	0.1	0.15	0.05	0.44	85
ZB-12	1 (z-2)	1.65	0.1	0.15	0.05	0.44	85
ZB-13	1 (z-2)	2.20	0.1	0.15	0.05	0.44	85

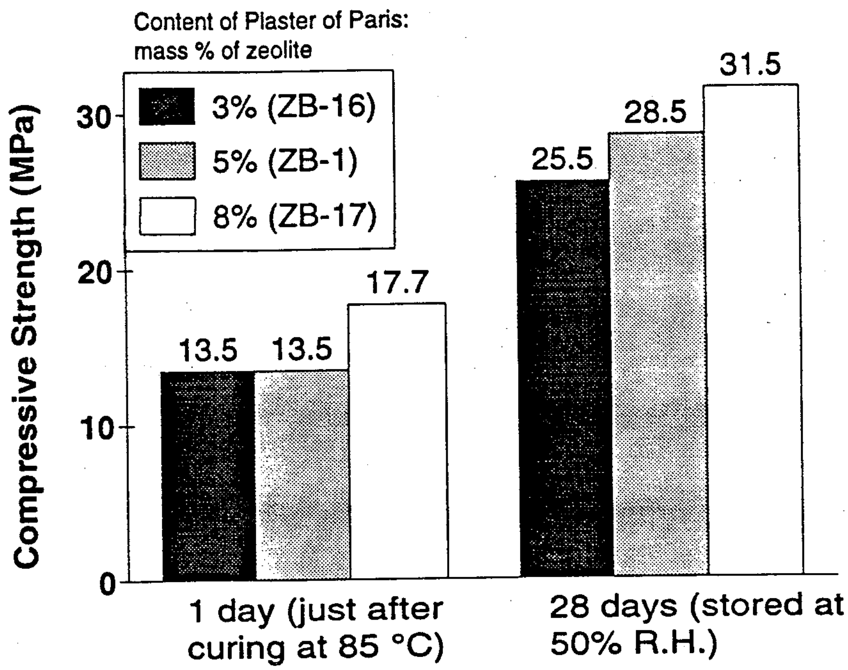
Fig. 12. Effect of aggregate content on compressive strength of concretes made with z-2 (initially cured at 85 °C and 100% R.H. for 16 hours during the first 24 hours and then stored at 23 °C and 50% R.H.).



Mixes: mass units

Spcimen	Zeolite (Type*)	Zeolite Aggregate	Portland Cement	Quick Lime	Plaster of Paris	Water	Curing Temp (°C)
ZB-7	1 (z-3)	1.10	0.1	0.15	0.05	0.44	85
ZB-14	1 (z-3)	1.65	0.1	0.15	0.05	0.44	85
ZB-15	1 (z-3)	2.20	0.1	0.15	0.05	0.44	85

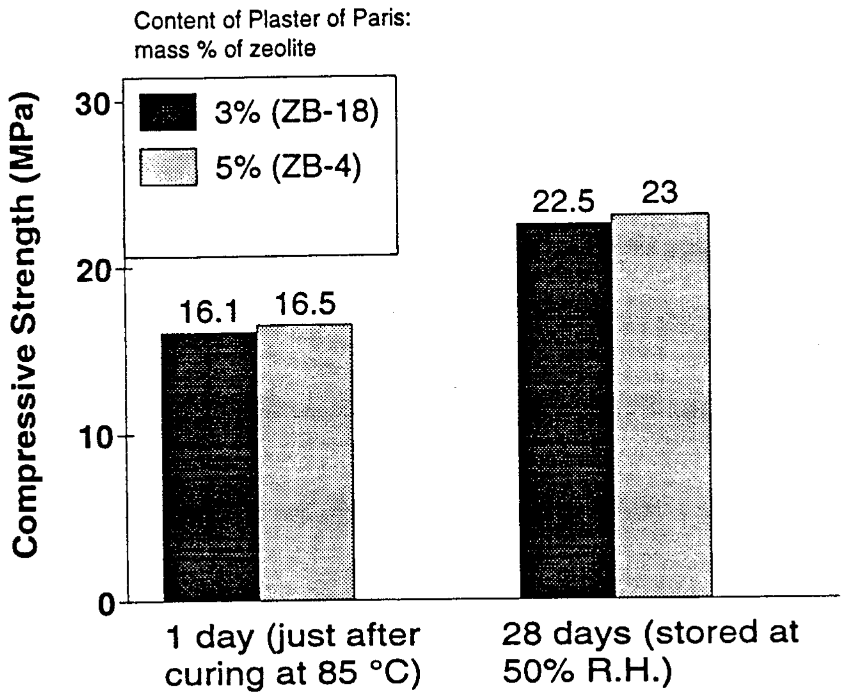
Fig. 13. Effect of aggregate content on compressive strength of concretes made with z-3 (initially cured at 85 °C and 100% R.H. for 16 hours during the first 24 hours and then stored at 23 °C and 50% R.H.).



Mixes: mass units

Spcimen	Zeolite (Type*)	Zeolite Aggregate	Portland Cement	Quick Lime	Plaster of Paris	Water	Curing Temp (°C)
ZB-16	1 (z-1)	1.10	0.1	0.15	0.03	0.44	85
ZB-1	1 (z-1)	1.10	0.1	0.15	0.05	0.44	85
ZB-17	1 (z-1)	1.10	0.1	0.15	0.08	0.44	85

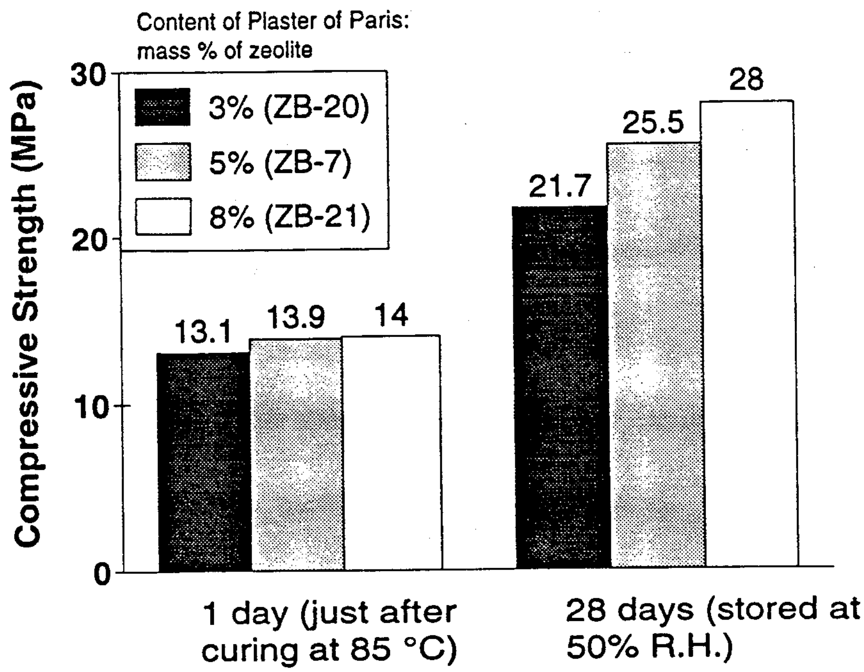
Fig. 14. Effect of plaster content on compressive strength of concretes made with z-1 (init)ally cured at 85 °C and 100% R.H. for 16 hours during the first 24 hours and then stored at 23 °C and 50% R.H.).



Mixes: mass units

Spcimen	Zeolite (Type*)	Zeolite Aggregate	Portland Cement	Quick Lime	Plaster of Paris	Water	Curing Temp (°C)
ZB-18	1 (z-2)	1.10	0.1	0.15	0.03	0.44	85
ZB-4	1 (z-2)	1.10	0.1	0.15	0.05	0.44	85

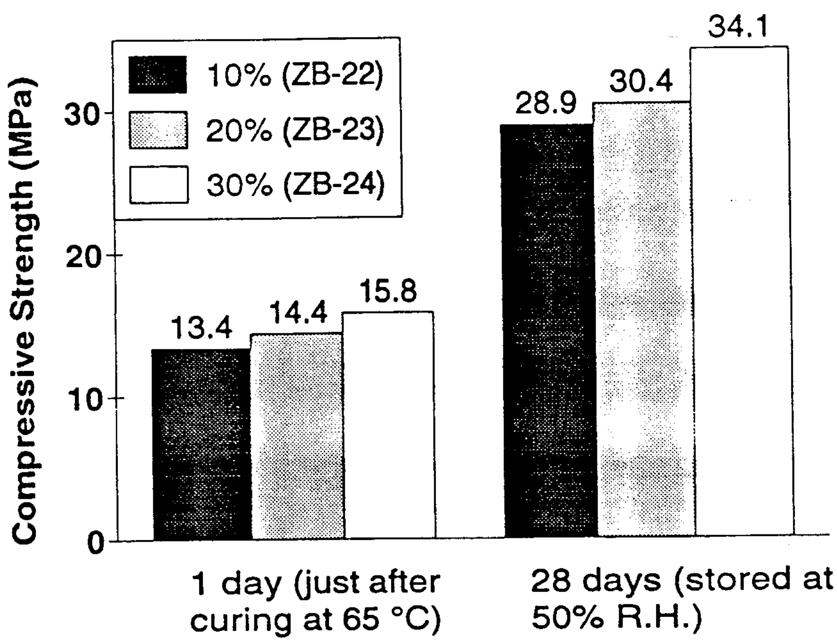
Fig. 15. Effect of plaster content on compressive strength of concretes made with z-2 (initially cured at 85 °C and 100% R.H. for 16 hours during the first 24 hours and then stored at 23 °C and 50% R.H.).



Mixes: mass units

Spcimen	Zeolite (Type*)	Zeolite Aggregate	Portland Cement	Quick Lime	Plaster of Paris	Water	Curing Temp (°C)
ZB-20	1 (z-3)	1.10	0.1	0.15	0.03	0.44	85
ZB-7	1 (z-3)	1.10	0.1	0.15	0.05	0.44	85
ZB-21	1 (z-3)	1.10	0.1	0.15	0.08	0.44	85

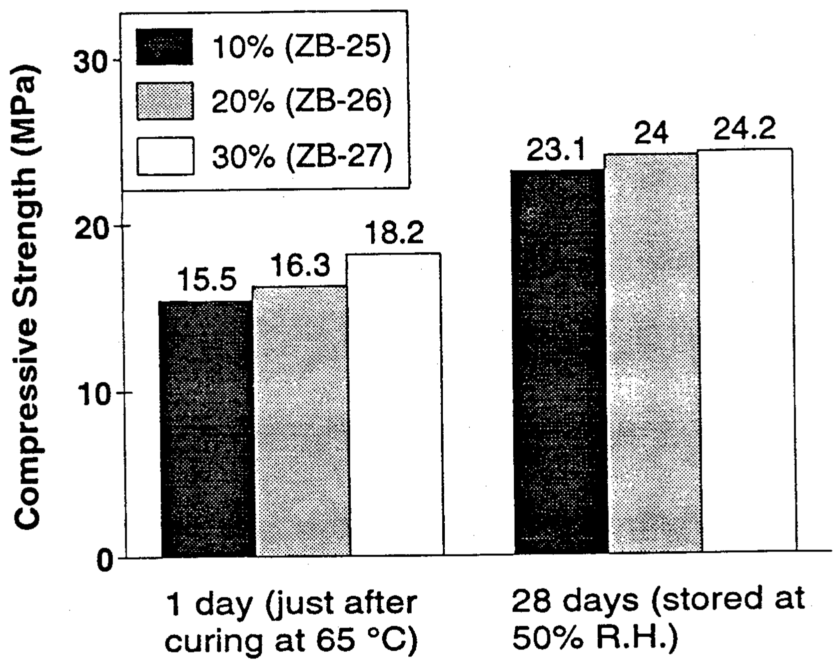
Fig. 16. Effect of plaster content on compressive strength of concretes made with z-3 (initially cured at 85 °C and 100% R.H. for 16 hours during the first 24 hours and then stored at 23 °C and 50% R.H.).



Mixes: mass units

Spcimen	Zeolite (Type*)	Zeolite Aggregate	Portland Cement	Quick Lime	Plaster of Paris	Water	Curing Temp (°C)
ZB-22	1 (z-1)	1.10	0.1	0.15	0.05	0.44	65
ZB-23	1 (z-1)	1.10	0.2	0.15	0.05	0.48	65
ZB-24	1 (z-1)	1.10	0.3	0.15	0.05	0.52	65

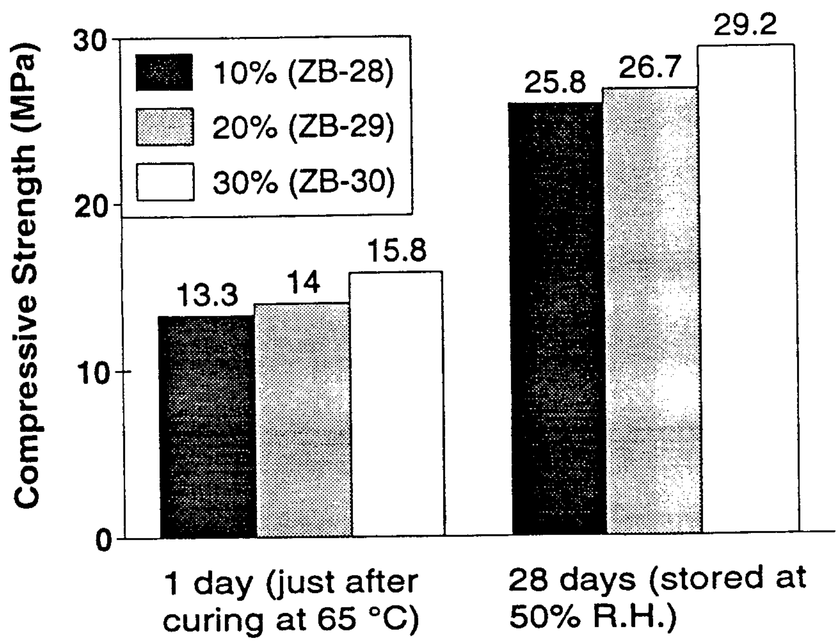
Fig. 17. Effect of cement content on compressive strength of concretes made with z-1 (initially cured at 65 °C and 100% R.H. for 16 hours during the first 24 hours and then stored at 23 °C and 50% R.H.).



Mixes: mass units

Spcimen	Zeolite (Type*)	Zeolite Aggregate	Portland Cement	Quick Lime	Plaster of Paris	Water	Curing Temp (°C)
ZB-25	1 (z-2)	1.10	0.1	0.15	0.05	0.44	65
ZB-26	1 (z-2)	1.10	0.2	0.15	0.05	0.48	65
ZB-27	1 (z-2)	1.10	0.3	0.15	0.05	0.52	65

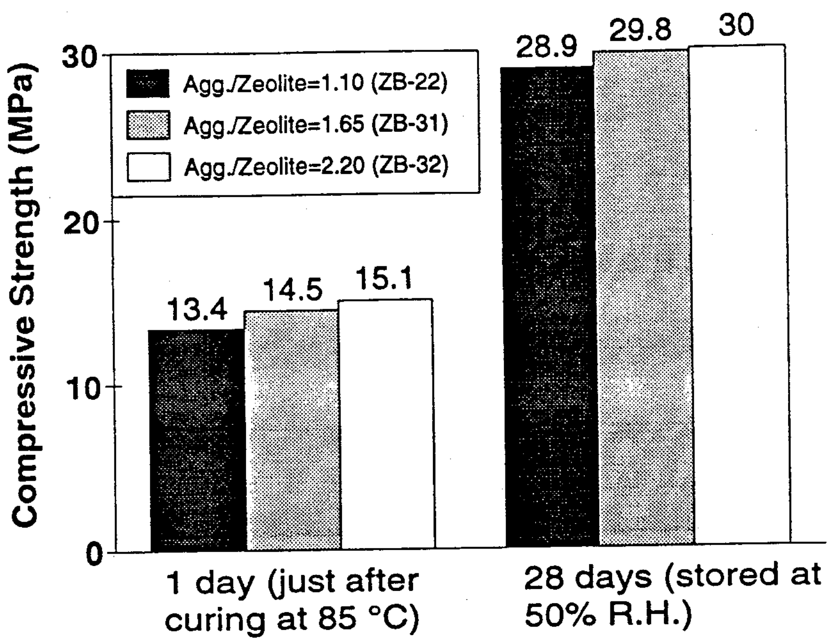
Fig. 18. Effect of cement content on compressive strength of concretes made with z-2 (initially cured at 65 °C and 100% R.H. for 16 hours during the first 24 hours and then stored at 23 °C and 50% R.H.).



Mixes: mass units

Spcimen	Zeolite (Type*)	Zeolite Aggregate	Portland Cement	Quick Lime	Plaster of Paris	Water	Curing Temp (°C)
ZB-28	1 (z-3)	1.10	0.1	0.15	0.05	0.44	65
ZB-29	1 (z-3)	1.10	0.2	0.15	0.05	0.48	65
ZB-30	1 (z-3)	1.10	0.3	0.15	0.05	0.52	65

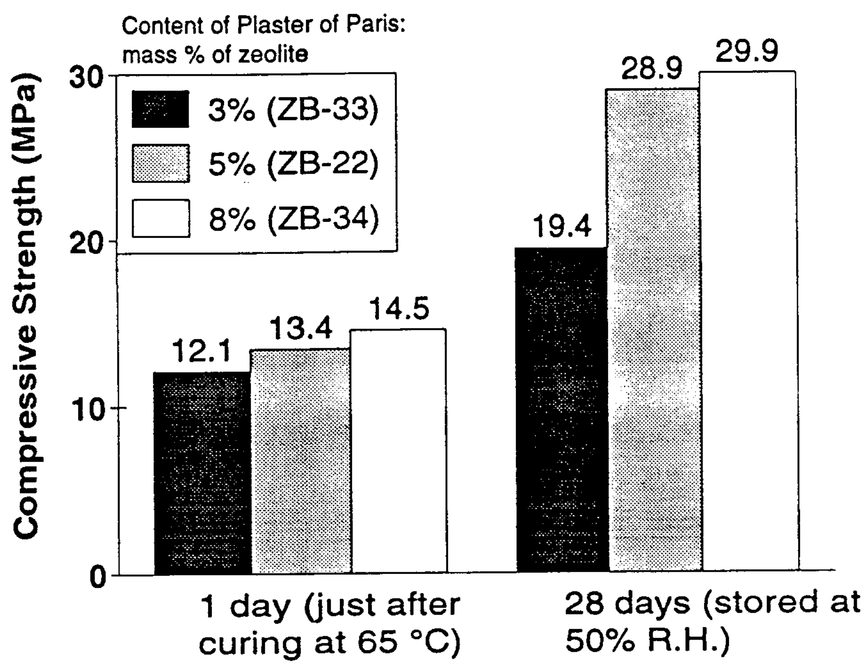
Fig. 19. Effect of cement content on compressive strength of concretes made with z-3 (initially cured at 65 °C and 100% R.H. for 16 hours during the first 24 hours and then stored at 23 °C and 50% R.H.).



Mixes: mass units

Spcimen	Zeolite (Type*)	Zeolite Aggregate	Portland Cement	Quick Lime	Plaster of Paris	Water	Curing Temp (°C)
ZB-22	1 (z-1)	1.10	0.1	0.15	0.05	0.44	65
ZB-31	1 (z-1)	1.65	0.1	0.15	0.05	0.44	65
ZB-32	1 (z-1)	1.20	0.1	0.15	0.05	0.44	65

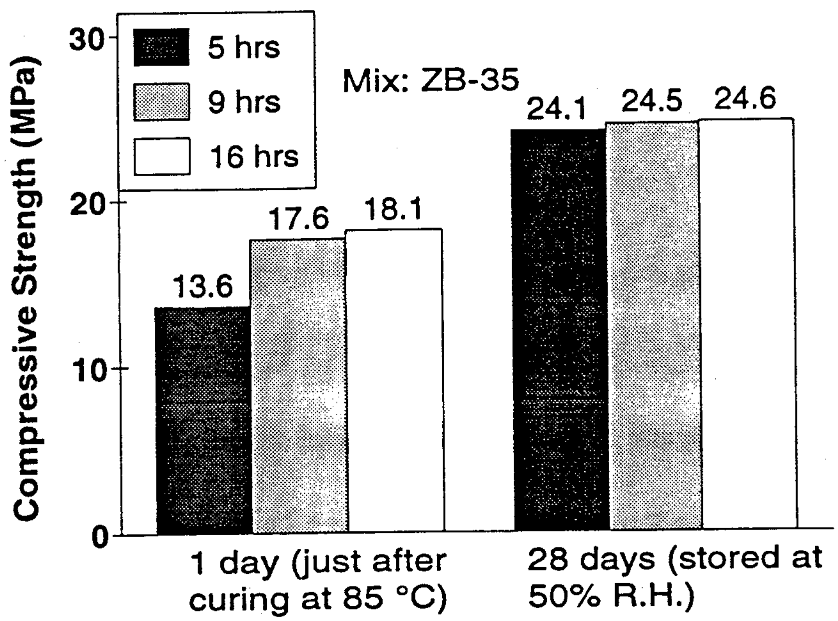
Fig. 20. Effect of aggregate content on compressive strength of concretes made with z-1 (initially cured at 65 °C and 100% R.H. for 16 hours during the first 24 hours and then stored at 23 °C and 50% R.H.).



Mixes: mass units

Spcimen	Zeolite (Type*)	Zeolite Aggregate	Portland Cement	Quick Lime	Plaster of Paris	Water	Curing Temp (°C)
ZB-33	1 (z-1)	1.10	0.1	0.15	0.03	0.44	65
ZB-22	1 (z-1)	1.10	0.1	0.15	0.05	0.44	65
ZB-34	1 (z-1)	1.10	0.1	0.15	0.08	0.44	65

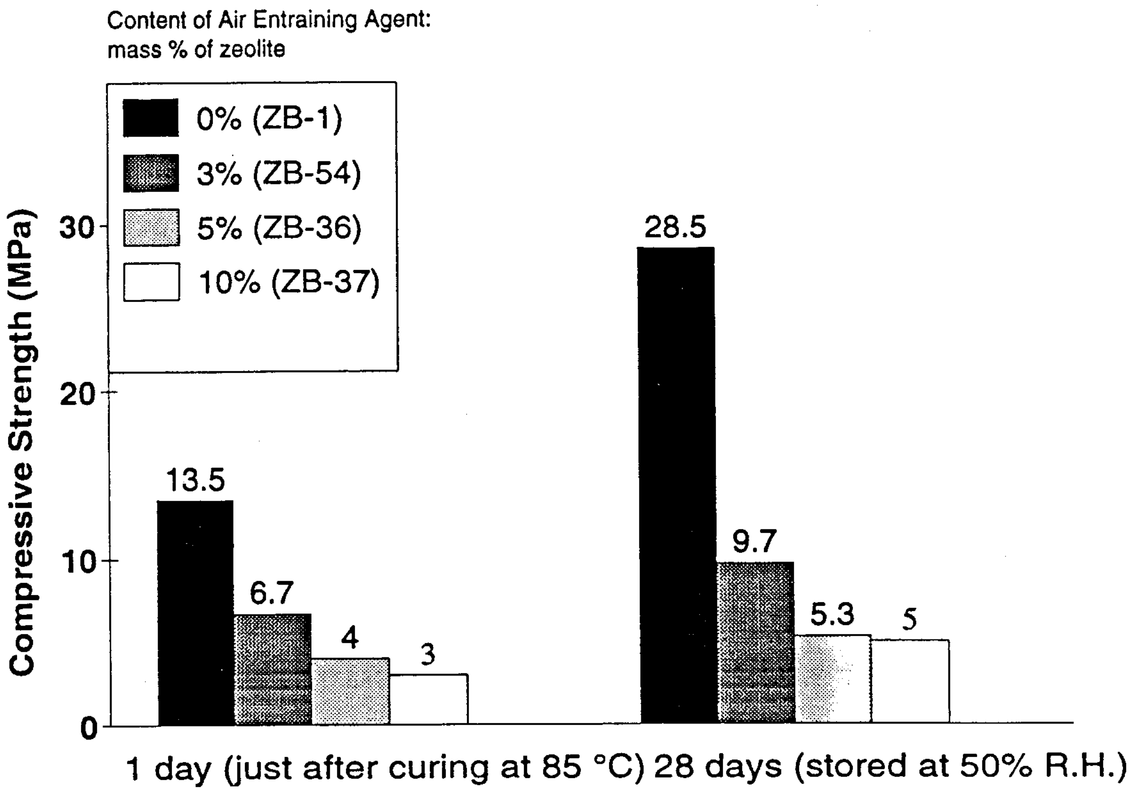
Fig. 21. Effect of plaster content on compressive strength of concretes made with z-1 (initially cured at 65 °C and 100% R.H. for 16 hours during the first 24 hours and then stored at 23 °C and 50% R.H.).



Mixes: mass units

Spcimen	Zeolite (Type*)	Zeolite Aggregate	Portland Cement	Quick Lime	Plaster of Paris	Water	Curing Temp (°C)
ZB-35	1 (z-1)	1.10	0.1	0.15	0.05	0.44	80-85

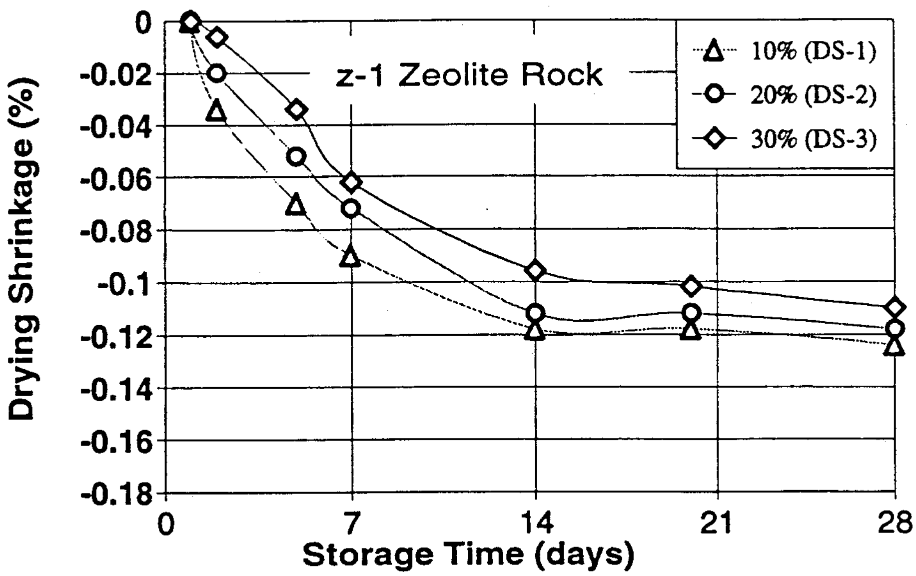
Fig. 22. Effect of a high temperature curing period on compressive strength of concretes made with z-1 (initially cured at 80-85 °C and 100% R.H. for 16 hours during the first 24 hours and then stored at 23 °C and 50% R.H.).



Mixes: mass units

Spcimen	Zeolite (Type*)	Zeolite Aggregate	Portland Cement	Quick Lime	Plaster of Paris	Air Entraining Agent	Water	Curing Temp (°C)
ZB-1	1 (z-1)	1.10	0.1	0.15	0.05	0	0.44	85
ZB-44	1 (z-1)	1.10	0.1	0.15	0.05	0.03	0.41	85
ZB-36	1 (z-1)	1.10	0.1	0.15	0.05	0.05	0.39	85
ZB-37	1 (z-1)	1.10	0.1	0.15	0.05	0.10	0.34	85

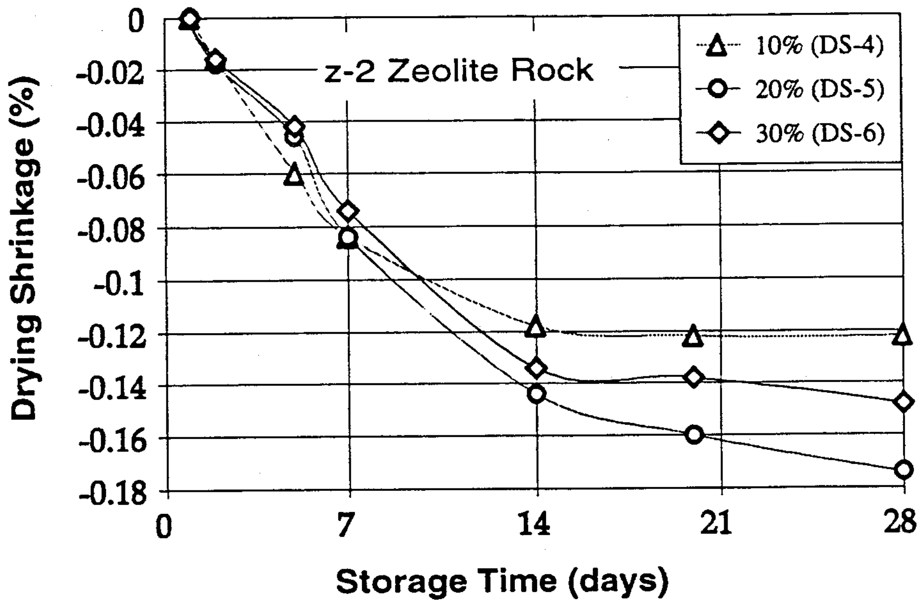
Fig. 23. Effect of the content of a air entraining agent on the compressive strength of concretes made with z-1 (initially cured at 85 °C and 100% R.H. for 16 hours during the first 24 hours and then stored at 23 °C and 50% R.H.).



Mixes: mass units

Spcimen	Zeolite (Type*)	Zeolite Aggregate	Portland Cement	Quick Lime	Plaster of Paris	Water	Curing Temp (°C)
DS-1	1 (z-1)	1.10	0.1	0.15	0.05	0.44	85
DS-2	1 (z-1)	1.10	0.2	0.15	0.05	0.48	85
DS-3	1 (z-1)	1.10	0.3	0.15	0.05	0.52	85

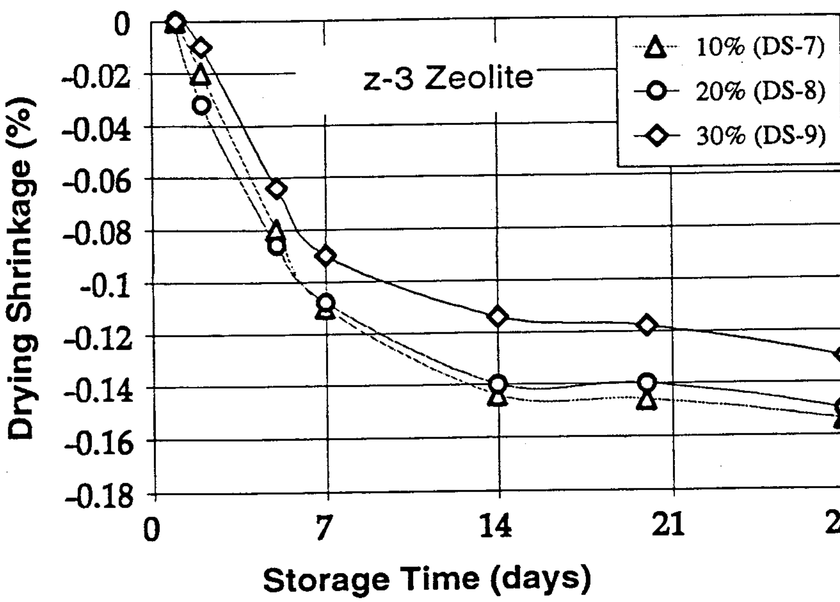
Fig. 24. Effect of cement content on drying shrinkage of concretes stored at 23 °C and 50% R,H. (made with z-1 and initially cured at 85 °C and 100% R.H.).



Mixes: mass units

Spcimen	Zeolite (Type*)	Zeolite Aggregate	Portland Cement	Quick Lime	Plaster of Paris	Water	Curing Temp (°C)
DS-4	1 (z-2)	1.10	0.1	0.15	0.05	0.44	85
DS-5	1 (z-2)	1.10	0.2	0.15	0.05	0.48	85
DS-6	1 (z-2)	1.10	0.3	0.15	0.05	0.52	85

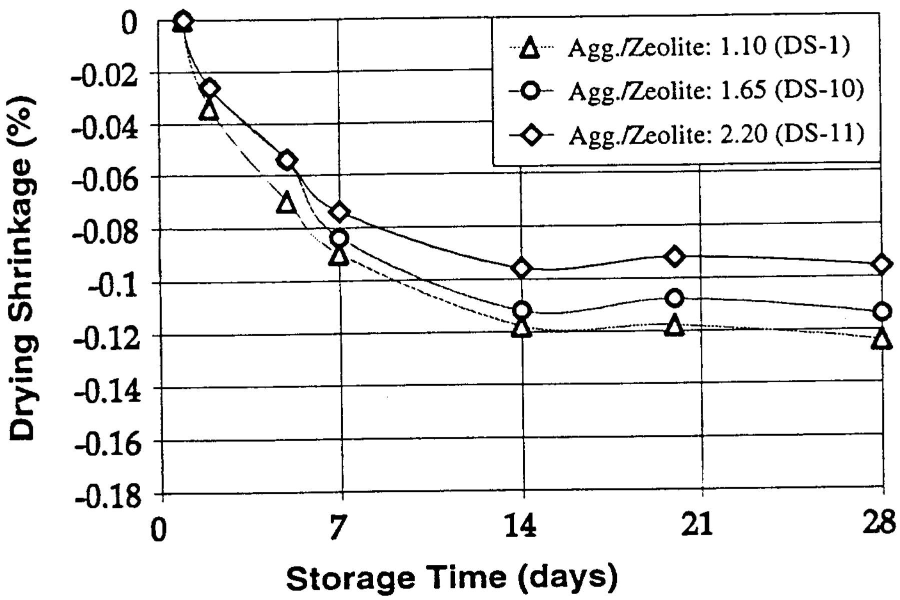
Fig. 25. Effect of cement content on drying shrinkage of concretes stored at 23 °C and 50% R,H. (made with z-2 and initially cured at 85 °C and 100% R.H.).



Mixes: mass units

Spcimen	Zeolite (Type*)	Zeolite Aggregate	Portland Cement	Quick Lime	Plaster of Paris	Water	Curing Temp (°C)
DS-7	1 (z-3)	1.10	0.1	0.15	0.05	0.44	85
DS-8	1 (z-3)	1.10	0.2	0.15	0.05	0.48	85
DS-9	1 (z-3)	1.10	0.3	0.15	0.05	0.52	85

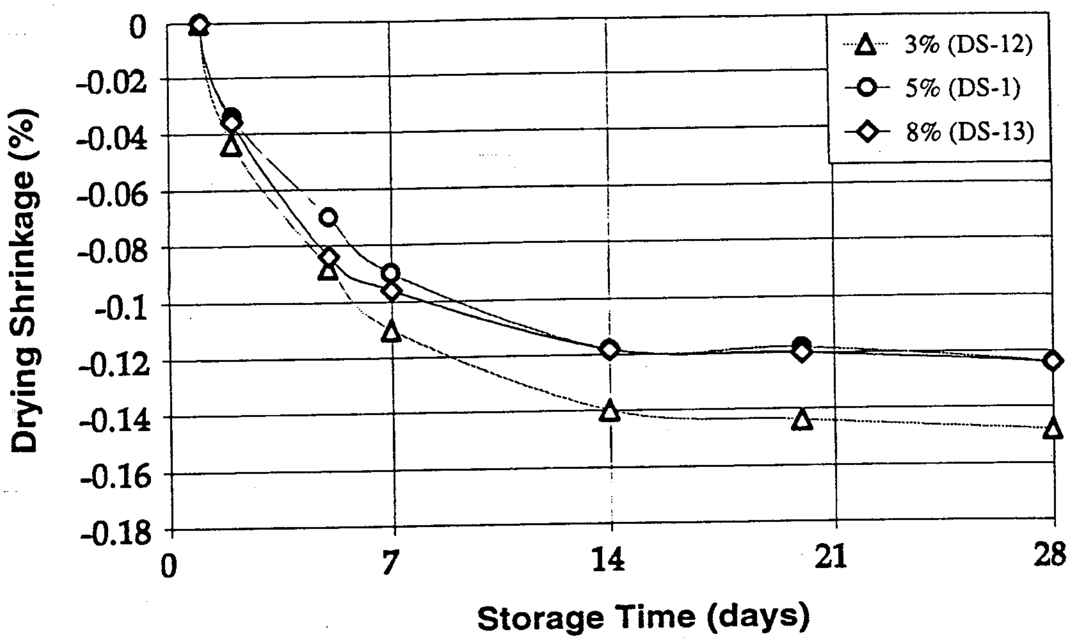
Fig. 26. Effect of cement content on drying shrinkage of concretes stored at 23 °C and 50% R,H. (made with z-3 and initially cured at 85 °C and 100% R.H.).



Mixes: mass units

Spcimen	Zeolite (Type*)	Zeolite Aggregate	Portland Cement	•uick Lime	Plaster of Paris	Water	Curing Temp (°C)
DS-1	1 (z-1)	1.10	0.1	0.15	0.05	0.44	85
DS-10	1 (z-1)	1.65	0.1	0.15	0.05	0.44	85
DS-11	1 (z-1)	2.20	0.1	0.15	0.08	0.44	85

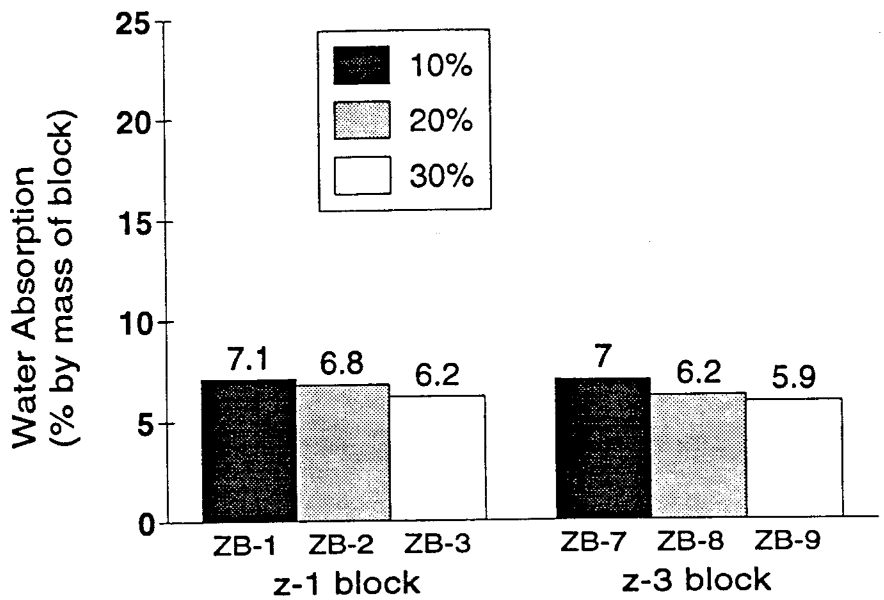
Fig. 27. Effect of aggregate content on drying shrinkage of concretes stored at 23 °C and 50% R,H. (made with z-1 and initially cured at 85 °C and 100% R.H.).



Mixes: mass units

Spcimen	Zeolite (Type*)	Zeolite Aggregate	Portland Cement	Quick Lime	Plaster of Paris	Water	Curing Temp (°C)
DS-12	1 (z-1)	1.10	0.1	0.15	0.03	0.44	85
DS-1	1 (z-1)	1.10	0.1	0.15	0.05	0.44	85
DS-13	1 (z-1)	1.10	0.1	0.15	0.08	0.44	85

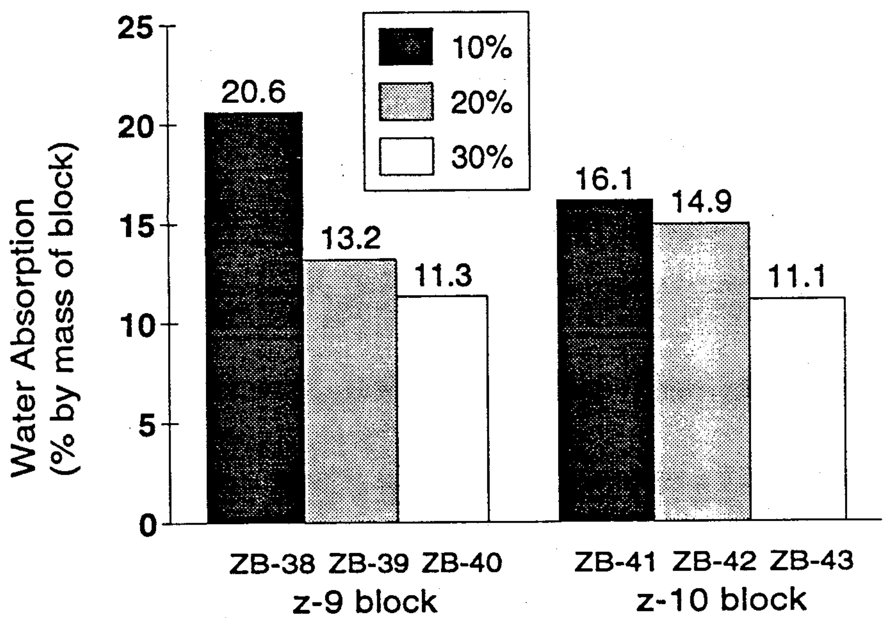
Fig. 28. Effect of plaster content on drying shrinkage of concretes stored at 23 °C and 50% R,H. (made with z-1 and initially cured at 85 °C and 100% R.H.).



Mixes: mass units

Spcimen	Zeolite (Type*)	Zeolite Aggregate	Portland Cement	Quick Lime	Plaster of Paris	Water	Curing Temp (°C)
ZB-1	1 (z-1)	1.10	0.1	0.15	0.05	0.44	85
ZB-2	1 (z-1)	1.10	0.2	0.15	0.05	0.48	85
ZB-3	1 (z-1)	1.10	0.3	0.15	0.05	0.52	85
ZB-7	1 (z-3)	1.10	0.1	0.15	0.05	0.44	85
ZB-8	1 (z-3)	1.10	0.2	0.15	0.05	0.48	85
ZB-9	1 (z-3)	1.10	0.3	0.15	0.05	0.52	85

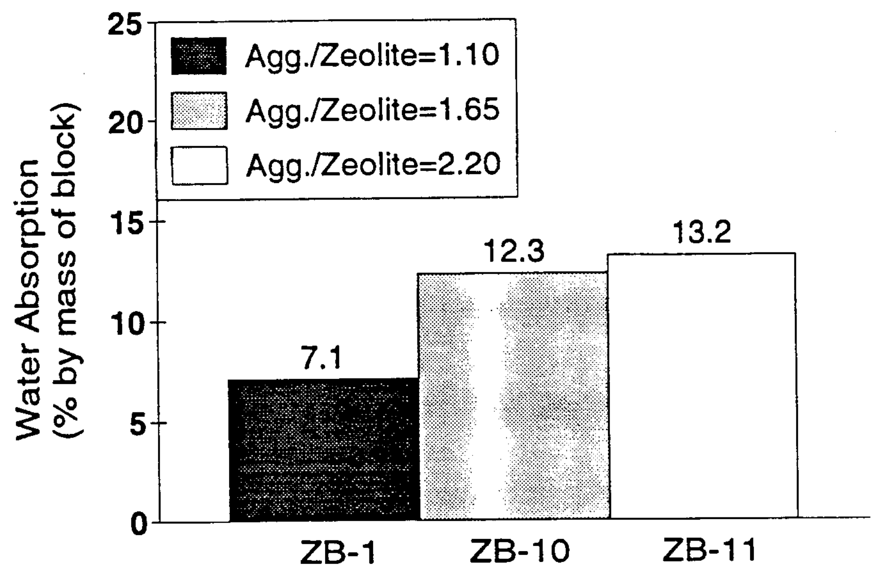
Fig. 29. Effect of cement content on water absorption by concretes made with z-1 or z-3.



Mixes: mass units

Spcimen	Zeolite (Type*)	Zeolite Aggregate	Portland Cement	Quick Lime	Plaster of Paris	Water	Curing Temp (°C)
ZB-38	1 (z-9)	1.10	0.1	0.15	0.05	0.77	85
ZB-39	1 (z-9)	1.10	0.2	0.15	0.05	0.84	85
ZB-40	1 (z-9)	1.10	0.3	0.15	0.05	0.91	85
ZB-41	1 (z-10)	1.10	0.1	0.15	0.05	0.77	85
ZB-42	1 (z-10)	1.10	0.2	0.15	0.05	0.84	85
ZB-43	1 (z-10)	1.10	0.3	0.15	0.05	0.91	85

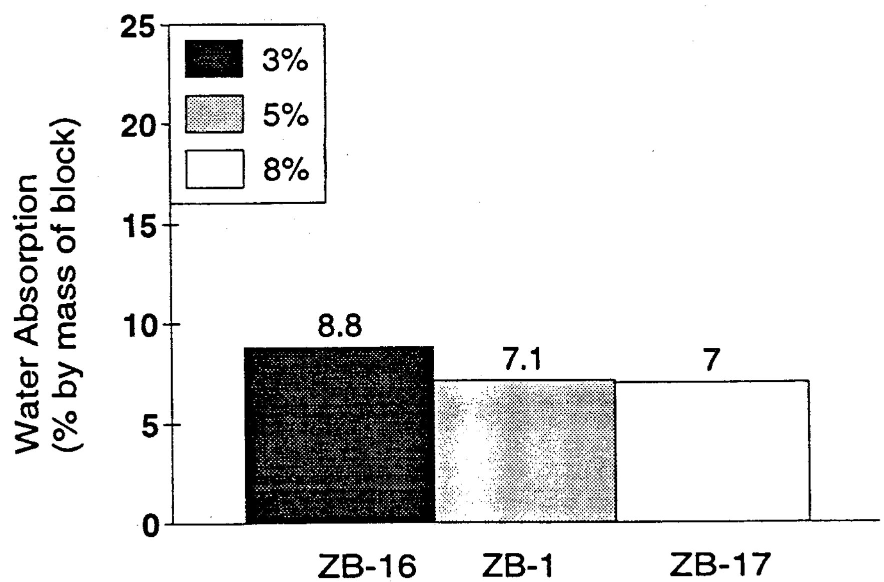
Fig. 30. Effect of cement content on water absorption by concretes made with z-9 or z-10.



Mixes: mass units

Spcimen	Zeolite (Type*)	Zeolite Aggregate	Portland Cement	Quick Lime	Plaster of Paris	Water	Curing Temp (°C)
ZB-1	1 (z-1)	1.10	0.1	0.15	0.05	0.44	85
ZB-10	1 (z-1)	1.65	0.1	0.15	0.05	0.44	85
ZB-11	1 (z-1)	1.20	0.1	0.15	0.05	0.44	85

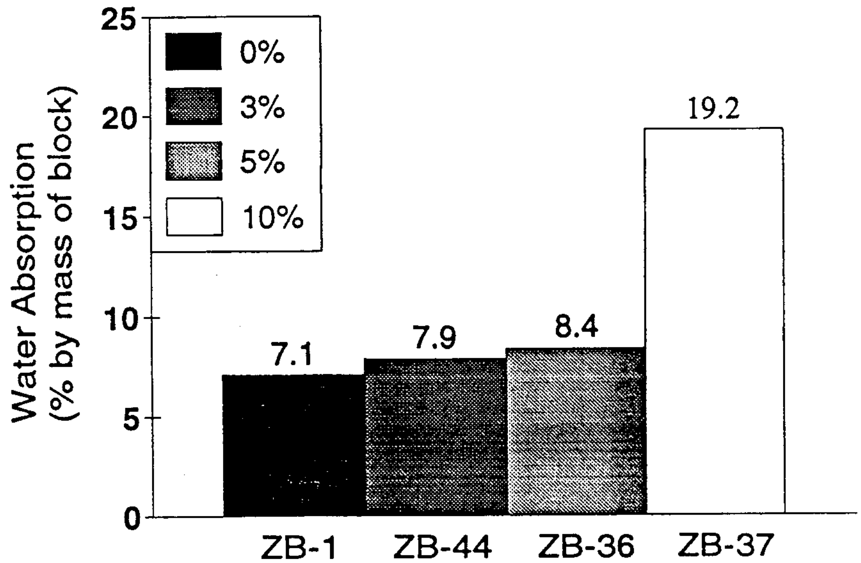
Fig. 31. Effect of aggregate content on water absorption by concretes made with z-1.



Mixes: mass units

Spcimen	Zeolite (Type*)	Zeolite Aggregate	Portland Cement	Quick Lime	Plaster of Paris	Water	Curing Temp (°C)
ZB-16	1 (z-1)	1.10	0.1	0.15	0.03	0.44	85
ZB-1	1 (z-1)	1.10	0.1	0.15	0.05	0.44	85
ZB-17	1 (z-1)	1.10	0.1	0.15	0.08	0.44	85

Fig. 32. Effect of plaster content on water absorption by concretes made with z-1.



Mixes: mass units

Spcimen	Zeolite (Type*)	Zeolite Aggregate	Portland Cement	Quick Lime	Plaster of Paris	Air Entraining Agent	Water	Curing Temp (°C)
ZB-1	1 (z-1)	1.10	0.1	0.15	0.05	0	0.44	85
ZB-44	1 (z-1)	1.10	0.1	0.15	0.05	0.03	0.41	85
ZB-36	1 (z-1)	1.10	0.1	0.15	0.05	0.05	0.39	85
ZB-37	1 (z-1)	1.10	0.1	0.15	0.05	0.10	0.34	85

Fig. 33. Effect of air entraining agent on water absorption by concretes made with z-1.