EVALUATION OF THE DUGGAN TEST FOR CONCRETES MADE OF DIFFERENT TYPES OF CEMENTS

Final Report
For
MLR-97-8

July 2000

Highway Division

Iowa Department of Transportation

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July 7, 2000

TECHNICAL REPORT TITLE PAGE

1. REPORT NO.	2. REPORT DATE
MLR-97-8	July 7, 2000

3. TITLE AND SUBTITLE	4. TYPE OF REPORT & PERIOD COVERED
Evaluation of the Duggan Test for Concrete Made of Different Types of Cements	Final report, 1-97 to 7-00

5. AUTHOR(S)	6. PERFORMING ORGANIZATION ADDRESS
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7. ACKNOWLEDGEMENT OF COOPERATING ORGANIZATIONS

8. ABSTRACT

In searching for simple and reliable test methods to evaluate the quality of Iowa portland cement concrete (PCC) pavements, the Duggan test was conducted for concretes made of twenty-six types of cements in this laboratory research. The influence of some factors, such as chemical composition and type of cements, use of air-entraining agent and water reducer, and water to cement ratio, on the result of the Duggan test was examined. It was found that the expansion increases with increasing values of potassium alkali (K_2O) and sulfur trioxide (SO_3) in cements. It was also found that the Type I cements generally produce higher expansion than the Type II, IP and IS cements. Since it is difficult to identify the major mechanism leading to the expansion observed in the Duggan test, more studies are certainly needed before it can be used as a reliable test method for evaluating the service life of concrete pavement.

9. KEY WORDS	10. NO. OF PAGE
Cement, concrete, Duggan Test Potassium alkali, sulfur trioxide Wet/dry cycling, microcracks Expansion, longevity of pavement	15

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DISCLAIMER

The contents of this report reflect the views of the authors and do not necessarily reflect the official views of the Iowa Department of Transportation. This report does not constitute any standard, specification or regulation.

INTRODUCTION

Portland cement concrete (PCC) pavements are widely used in Iowa highways. To ensure the longevity of PCC pavements, some simple and reliable test methods are needed for evaluating the quality of concrete.

Scott and Duggan (1986) had proposed a laboratory test method for the detection of potentially deleterious expansion of concrete. They tried to correlate the measured expansion to the field performance of concrete. Although some studies have been performed to understand the Duggan test, there are different opinions on the major mechanisms leading to the expansion measured in the test. Scott and Duggan (1986) originally reported that the expansion might be primarily due to the alkali-silica reaction in concrete. However, based on the microscopic examination of the specimens for the Duggan test, Grabowski et al. (1992) suggested that the delayed-ettringite formation might be the main cause of the expansion. Idorn and Skalny (1993) argued that oven-drying of small core specimens according to the Duggan test may significantly weaken the microstructure of the matrix in concrete so that it becomes vulnerable to other physical and chemical attacks.

The objective of this study is to evaluate the Duggan test for various concrete mixtures. Twenty-six cements were used to cast the concretes. The correlation between the expansion measured and the chemical components of the cements used to make the concretes was developed. The influence of air-entraining agent, water reducer, and the water to cement ratio was evaluated.

MATERIALS, SPECIMENS AND TEST PROCEDURE

Twenty-six cements were used. These cements include ASTM Types I, II, III, IP and IS. The chemical properties of these cements are listed in Table 1. The limestone coarse aggregate, which has the top size of ½ inch, and the sand used are durable and have good service life. Iowa Department of Transportation Standard Mix C-3 was used as the basis for all mixtures tested. The mixture proportion for Mix C-3 includes 603 lb. of cement, 1817 lb. of coarse aggregate, 1483 lb. of sand for per cubic yard of concrete. The water to cement ratio for the mixture is 0.45.

According to the test procedure developed by Scott and Duggan (1986), a 4 x 8-in. concrete cylinder was cast for each mixture. The cylinders obtained were stored in a moist room (73 ± 3°F and above 95% humidity) for 28 days. Five cores, which are one inch in diameter and two inches in length, were drilled from each cylinder. The cores were treated by three alternative cycles of wetting (24–72 hours at 72°F) and oven drying (24-72 hours at 180°F). The cores were then immersed in the distilled water and the expansion was measured up to another 20 days. Each value of the expansion given in this report was the average of five samples. The obtained results will be discussed later.

RESULTS AND DISCUSSION

Effect of Cement Type

Relationships between cement type and the Duggan expansion are discussed in this section. To examine the influence of chemical components of cements, the results presented in the section are measured based on the non air-entrained concrete. No chemical and mineral admixtures were used in these concretes. The type of cements is the only variation of materials in these concretes.

The Duggan expansion measured is plotted against various chemical components of the cements in Figs. 1-8. The results of the concretes using Type IP or IS cement are not included in Figs. 1-8. The expansion is fairly well correlated to either potassium alkali, K_2O (see Fig. 1), or sulfur trioxide, SO_3 (see Fig. 2). The correlation coefficients, R^2, for K_2O and SO_3 are equal to 0.773 and 0.732, respectively. Values of the expansion increase with increasing values of K_2O and SO_3. As shown in Figs. 3-8, the correlation between the expansion and other chemical components of the cements is insignificant.

Values of the measured expansion are plotted against types of cements in Fig. 9. The mixtures made of the ASTM Type I cements generally have the greatest expansion. As shown in the figure, when different Type I cements were used, the expansion values can change significantly. This may be explained by the fact that Type I cements have a wide range of chemical and physical properties. On the other hand, the mixtures using ASTM Type II cements normally have less expansion. The concretes made of the blended cements (ASTM Types IP and IS) show comparable values of the expansion to those using the Type II cements.

Effects of Air-Entraining Agent and Water Reducer

The influence of air-entraining agent (AEA) and water reducers (WR) on the expansion is shown in Fig. 10 for concretes using six different cements, respectively.

It is seen from the figure that when there is no water reducer in the mixtures, the air-entrained and non air-entrained concretes have basically identical expansion.

When there is no air-entraining agent in the mixtures, the effect of the water reducer on the expansion is dependent on each water reducer used. The addition of WR1 or WR2 seems to increase the expansion. The increase in the expansion is somewhat less significant when WR3 or WR4 is used.

For the mixtures with a water reducer, the use of the air-entraining agent generally reduces the expansion for the mixtures using cements 8, 16 and 19. On the other hand, the addition of the air-entraining agent seems to have little effect on the magnitude of the expansion for the mixtures using cements 7, 13 and 21.

Effect of Water/Cement Ratio

The influence of the water to cement ratio of concrete on the Duggan expansion is illustrated in Fig. 11 for the mixtures using cement 17 with K_2O = 0.92% and SO_3 = 4.1%. For the non air-entrained concrete, the higher the water to cement ratio, the greater the expansion. However, for the air-entrained concrete, the lower the water to cement ratio, the higher the expansion. As shown in Fig. 12, for the mixtures using cement 22 with K_2O = 0.32% and SO_3 = 1.6%, the effect of the water cement ratio on the expansion seems to be insignificant because the values of the expansion are much smaller than those shown in Fig. 11

Some Discussion

The alkali-silica reaction (Scott and Duggan, 1986) and the delayed-ettringite formation (Grabowski et. al., 1992) have previously been proposed to explain the observed expansion from the Duggan test. No direct attempt was tried to identify major mechanisms leading to the observed expansion in this study. It was noted that cycles of wetting and oven drying, up to 180°F during the Duggan treatment, can create a great amount of shrinkage and thermal microcracks in concrete. These microcracks can contribute to the observed expansion. There may be several mechanisms leading to the expansion observed in the Duggan test. It is difficult to identify which one is dominated in a certain environmental condition. As indicated by Idorn and Scanly (1993), the initial treatment of the test specimens had left their microstructure in such a weakened condition that no single cause of their degradation can be identified with any degree of certainty. Since major mechanisms leading to the expansion are not clearly understood, the Duggan test may not be suitable as a reliable test method to predict the service life of concrete until more studies are conducted.

SUMMARY

(1) Values of the Duggan expansion measured are correlated to the level of K_2O and SO_3 in cements that were used to make the concrete. The greater the level of K_2O or SO_3 in cements, the higher the expansion.

(2) Concrete made of Type I cement generally has greater expansion than those made of Types II, IP and IS cements.

(3) When water reducer is not used, air-entrained concrete has approximately identical value of the expansion compared to non air-entrained concrete using the same cement. For concrete using a water reducer, however, the addition of an air-entraining agent may slightly reduce the expansion

(4) When a cement with high levels of K_2O and SO_3 is used in non air-entrained concrete, the expansion increases as the water to cement ratio increases. However, for air-entrained

concrete, the expansion decreases with increasing values of the water to cement ratio. These trends are not significant for concrete using a cement with low levels of K_2O and SO_3 because its expansion is small.

(5) Since the mechanisms leading to the expansion observed in the Duggan test are not quite clear, more studies are certainly needed before it can be used as reliable test method for evaluating the service life of concrete pavement.

ACKNOWLEDGMENTS

The authors thank the Cement and Concrete Section of Iowa DOT Central Materials Laboratory for conducting the test. The authors also appreciate the input of C. Narotam, K. B. Jones, J. Grove, and W. Dubberke from the Iowa DOT.

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Idorn, G.M. and Skalny, J., (1993), Discussion of the Paper "Rapid Test of Concrete Expansivity due to Internal Sulfate Attack" by Grabowski et al., ACI Materials Journal, Vol. 90, No. 3, pp. 383-384.

TABLE TITLES

Table 1 Chemical Properties of Cements Used

Cement ID	Cement Type	MgO	SO_3	Fe_2O_3	Al_2O_3	CaO	Na_2O	K_2O	Alkali Equi.	C_3A
1	I	3.54	2.31	1.50	5.28	64.49	0.07	0.03	0.09	12.80
2	II	3.06	2.57	3.23	4.17	62.30	0.09	0.65	0.52	6.40
3	II	1.52	2.67	3.31	4.10	64.09	0.19	0.46	0.49	6.20
4	II	3.60	2.43	3.24	4.43	63.24	0.12	0.47	0.43	7.10
5	I	4.05	2.38	2.08	4.60	64.30	0.07	0.53	0.42	10.00
6	II	2.80	2.78	3.54	4.62	63.27	0.12	0.57	0.50	7.10
7	II	3.33	2.56	3.26	4.46	62.30	0.15	0.55	0.51	7.20
8	II	2.59	2.90	3.47	4.73	63.15	0.13	0.61	0.53	7.60
9	II	2.99	3.39	2.53	4.25	63.34	0.21	0.49	0.53	7.80
10	I	2.61	2.99	2.85	4.36	63.89	0.09	0.67	0.53	8.10
11	I	1.92	3.13	3.03	5.01	63.92	0.16	0.53	0.51	9.00
12	I	2.75	3.00	2.28	5.04	62.30	0.04	0.58	0.42	10.20
13	I	3.29	3.02	2.98	4.66	62.70	0.10	0.54	0.46	8.80
14	I	2.75	3.00	2.28	5.04	62.30	0.04	0.58	0.42	10.20
15	III	3.01	3.17	2.35	5.19	63.10	0.05	0.55	0.41	10.30
16	I	2.61	3.05	2.30	5.08	62.61	0.06	0.62	0.47	10.20
17	I	2.80	4.10	2.00	5.30	61.40	0.31	0.92	0.92	11.70
18	I	3.82	3.85	3.03	5.30	60.83	0.07	1.26	0.90	8.90
19	I	4.00	3.81	2.98	4.30	61.64	0.06	1.21	0.86	7.10
20	I	2.54	3.37	2.50	3.51	64.08	0.18	1.01	0.84	5.70
21	II	1.38	2.56	3.66	3.36	64.81	0.18	0.23	0.33	4.20
22	II	3.00	1.60	2.80	3.90	64.40	0.22	0.32	0.42	6.00
23	II	3.00	1.60	2.80	3.90	64.40	0.22	0.32	0.42	6.00
24	IP	2.02	3.09	3.68	9.77	52.61	0.10	0.40	0.36	--
25	IS	5.71	2.87	2.20	5.89	55.53	0.14	0.44	0.43	--
26	IS	6.48	3.36	2.15	5.86	54.63	0.14	0.91	0.74	--

FIGURE CAPTIONS

1. Effect of K_2O on Expansion
2. Effect of SO_3 on Expansion
3. Effect of Na_xO pm Expansion
4. Effect of MgOon Expansion
5. Effect of Al_2O_3 on Expansion
6. Effect of C_3A on Expansion
7. Effect of Fe_2O_3 on Expansion
8. Effect of CaO on Expansion
9. Effect of Cement Types on the Duggan Expansion
10. Effects of Air Entrained Agent (AEA) and Water Reducers (WR) on Expansion
11. Effect of Water/Cement Ratio on the Expansion for Mixes Using Cement With $K_2O = 0.92\%$ and $SO_3 = 4.1\%$
12. Effect of Water/Cement Ratio on the Expansion for Mixes Using Cement 22 With $K_2O = 0.32\%$ and $SO_3 = 1.6\%$

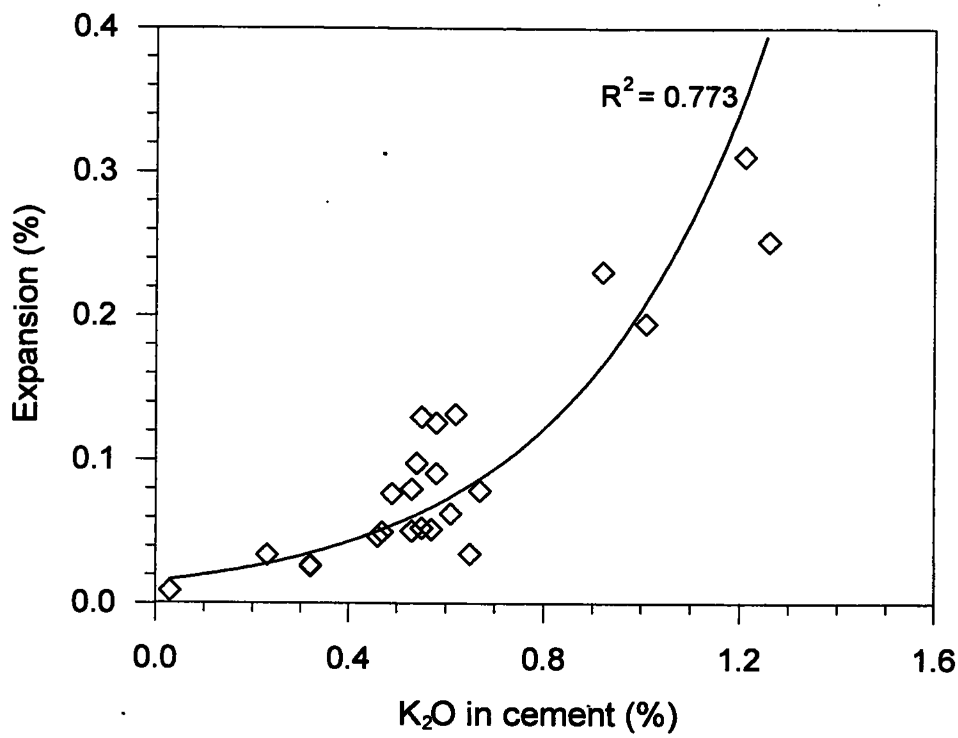


Fig. 1 Effect of K_2O on expansion

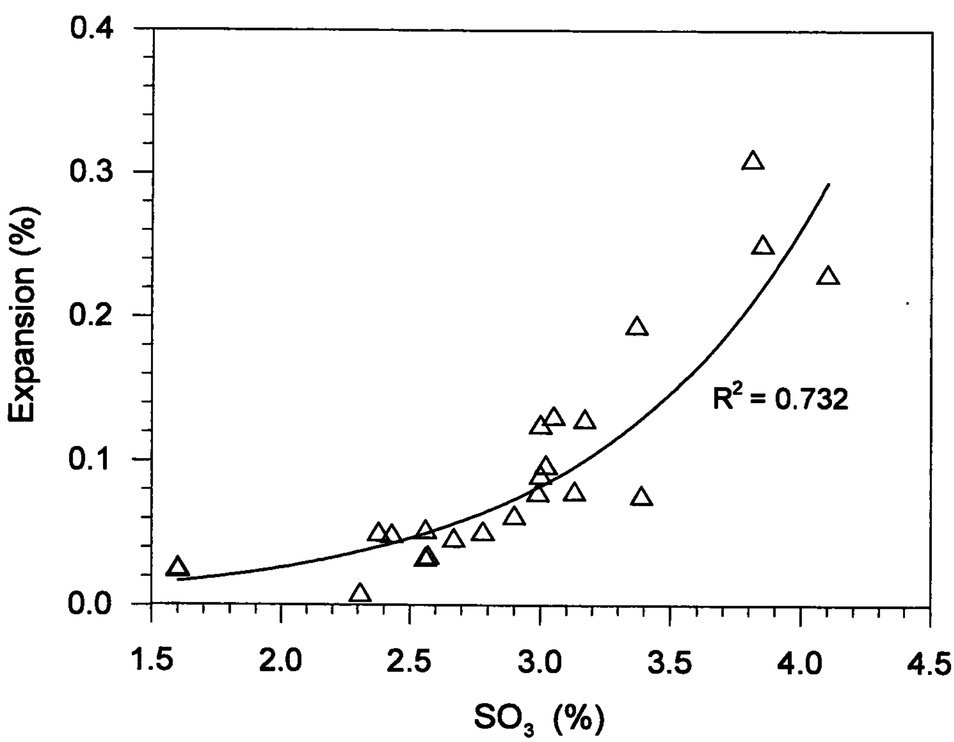


Fig. 2 Effect of SO_3 on expansion

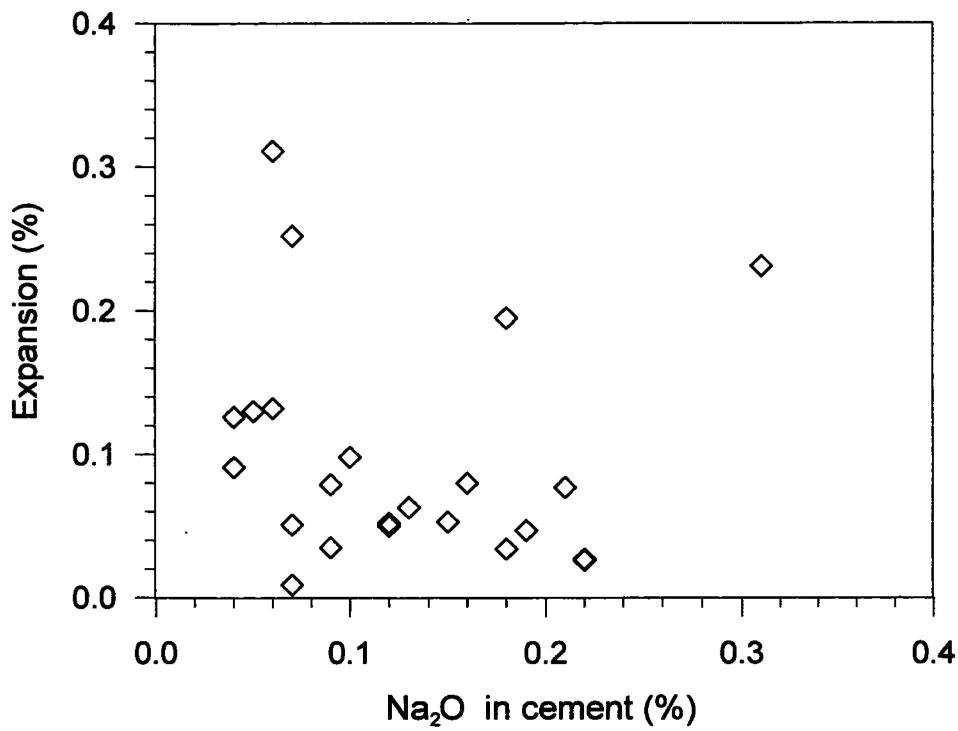


Fig. 3 Effect of Na_2O on expansion

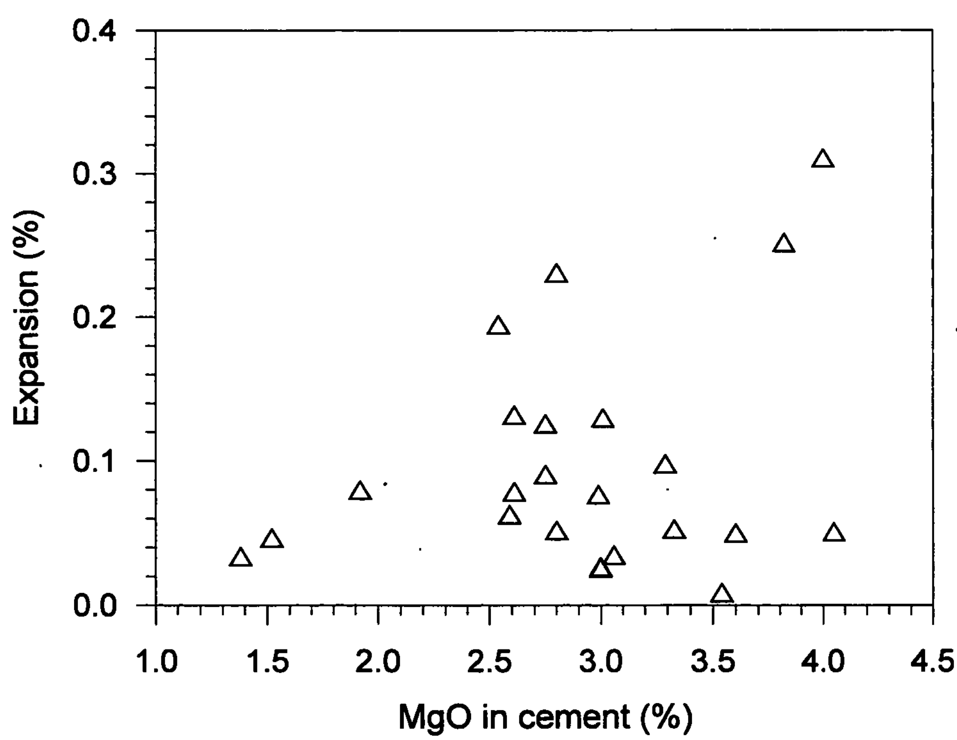


Fig. 4 Effect of MgO on expansion

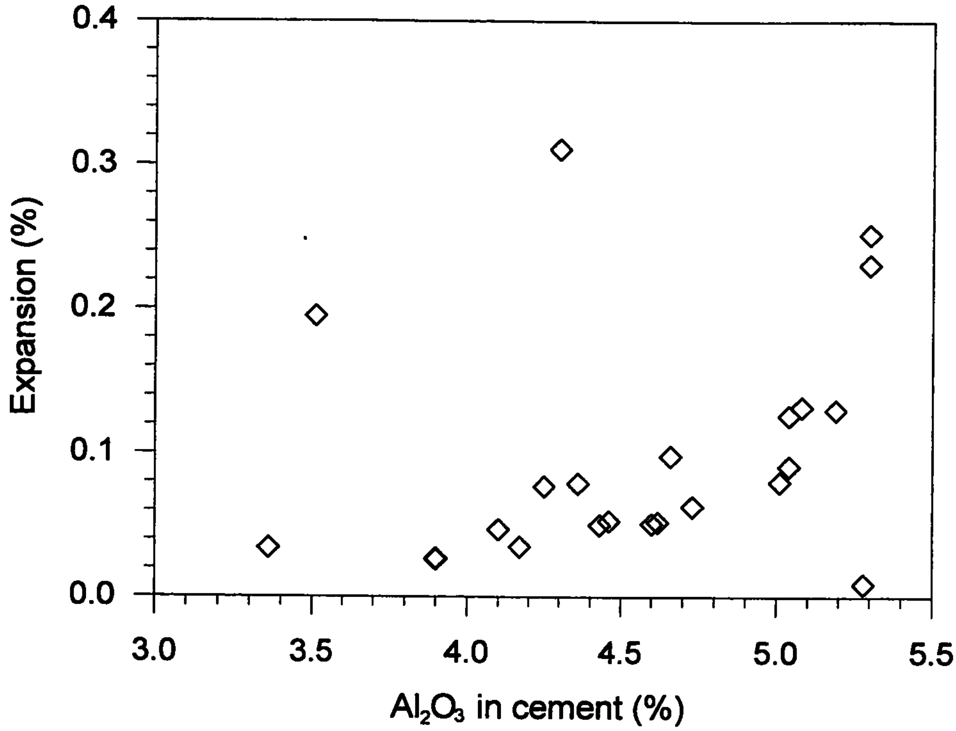


Fig. 5 Effect of Al_2O_3 on expansion

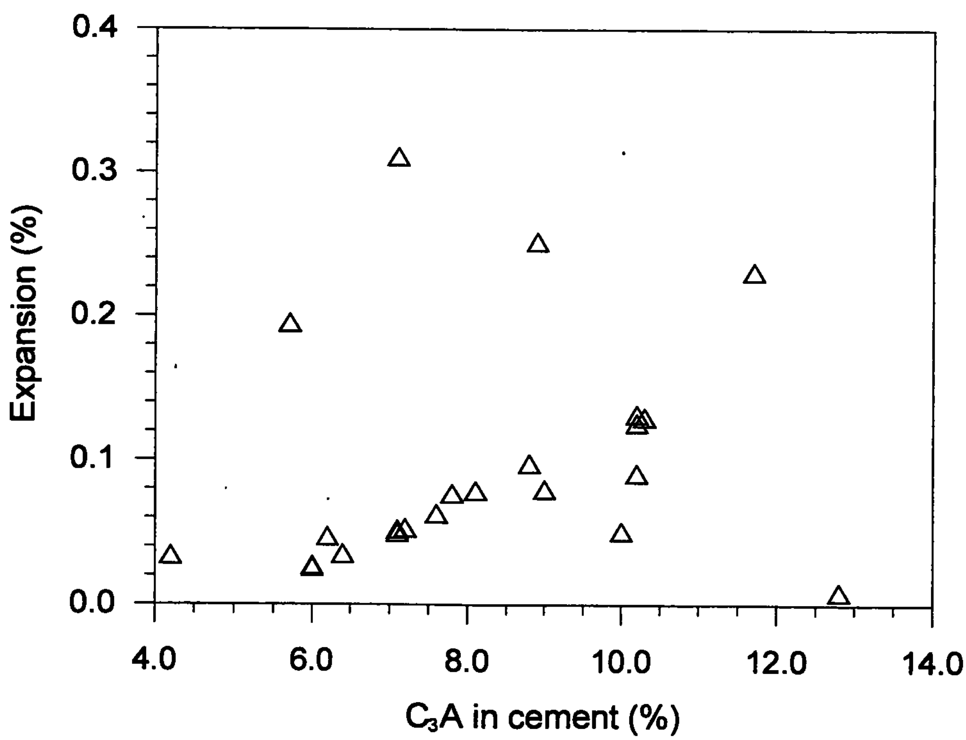


Fig. 6 Effect of C_3A on expansion

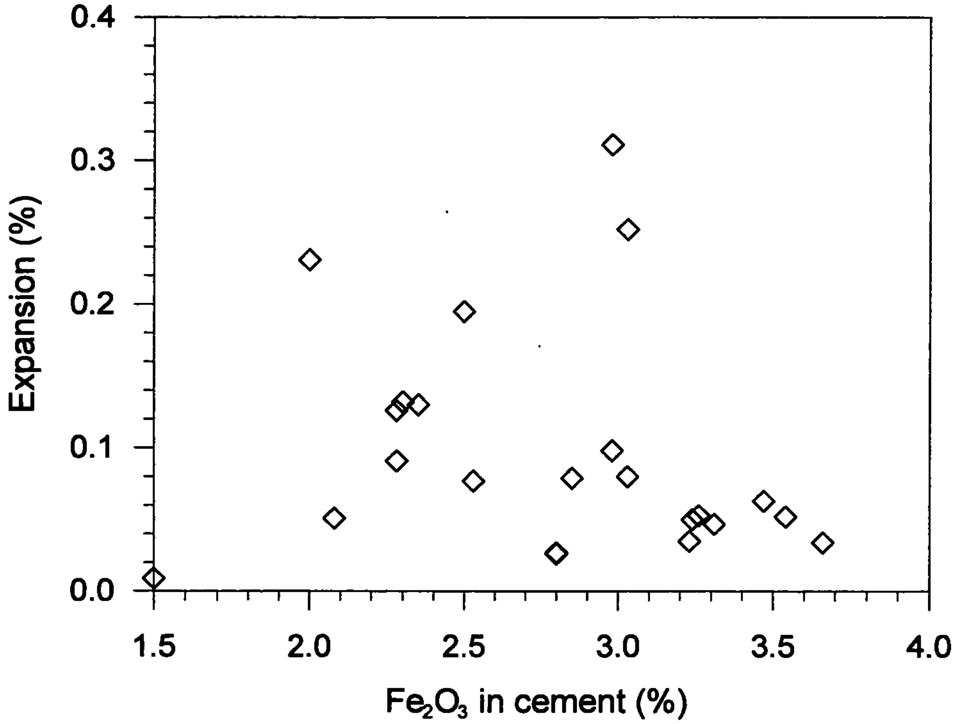


Fig. 7 Effect of Fe_2O_3 on expansion

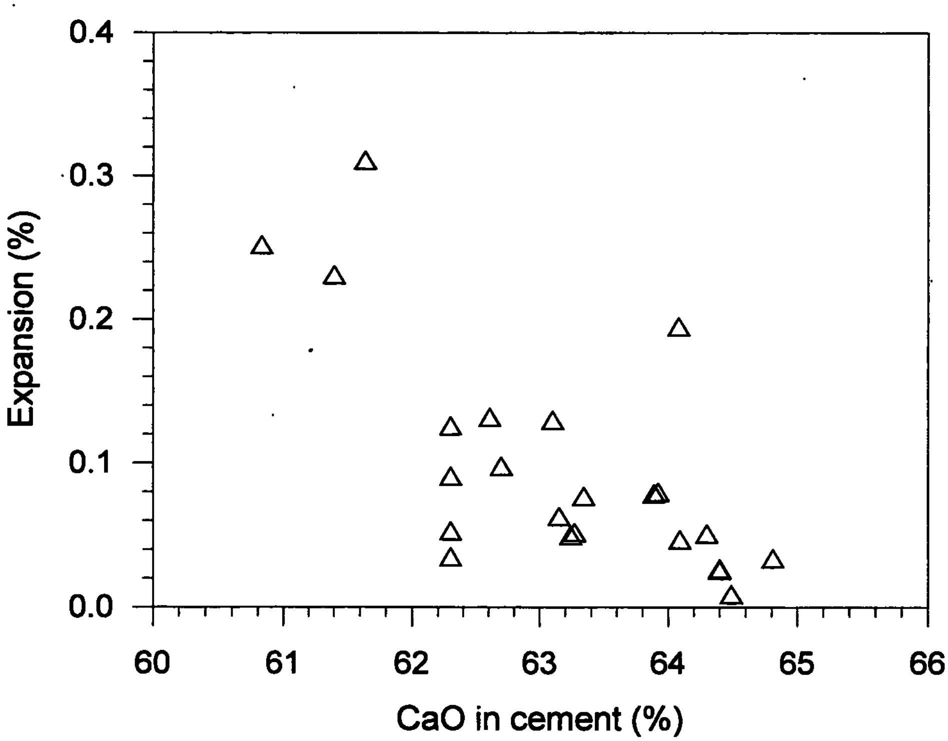


Fig. 8 Effect of CaO on expansion

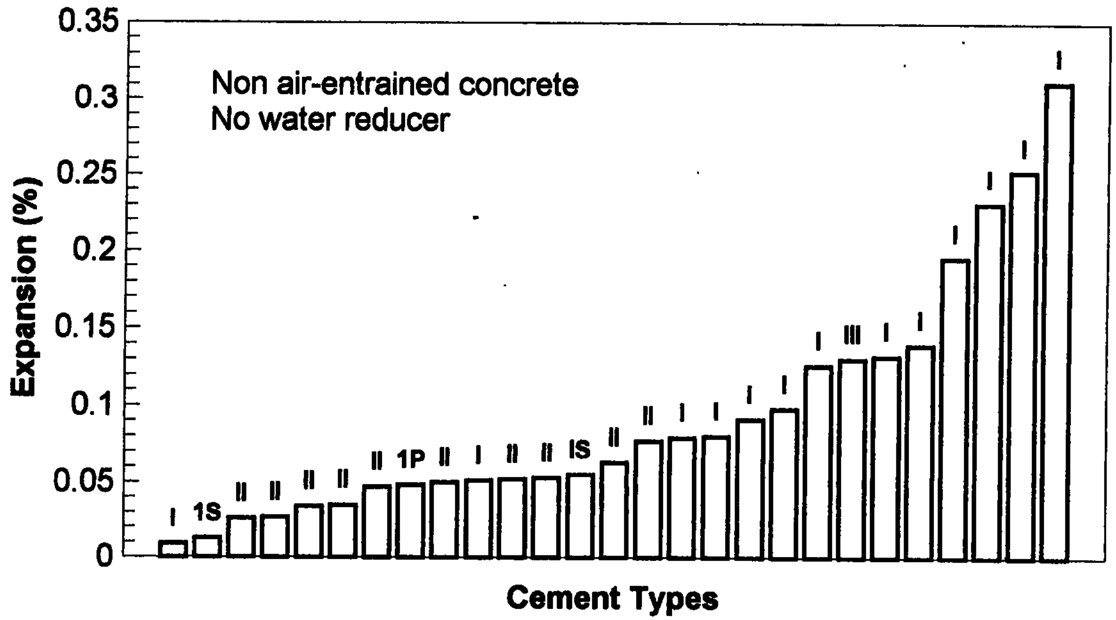


Fig. 9 Effect of cement types on the Duggan expansion

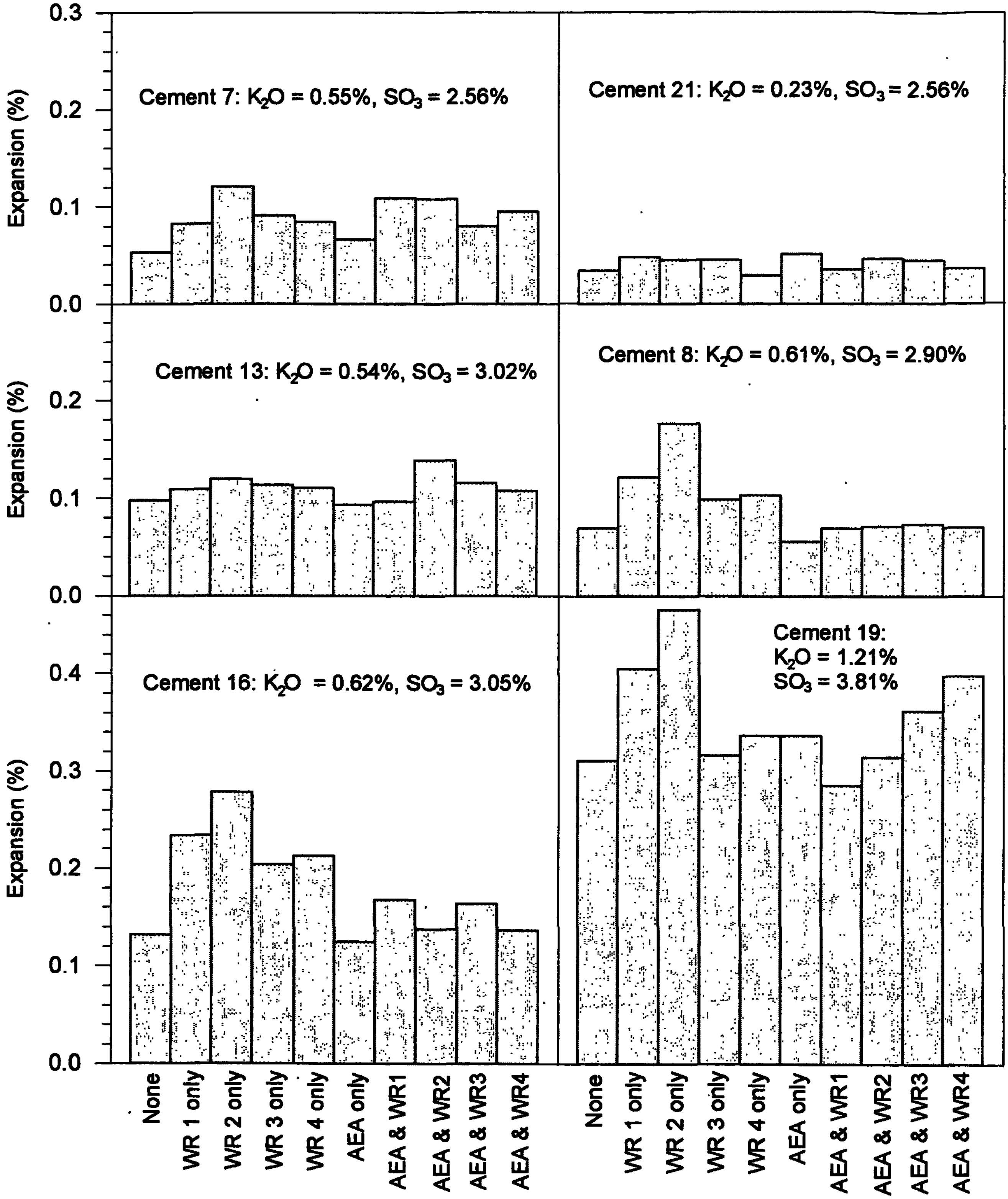
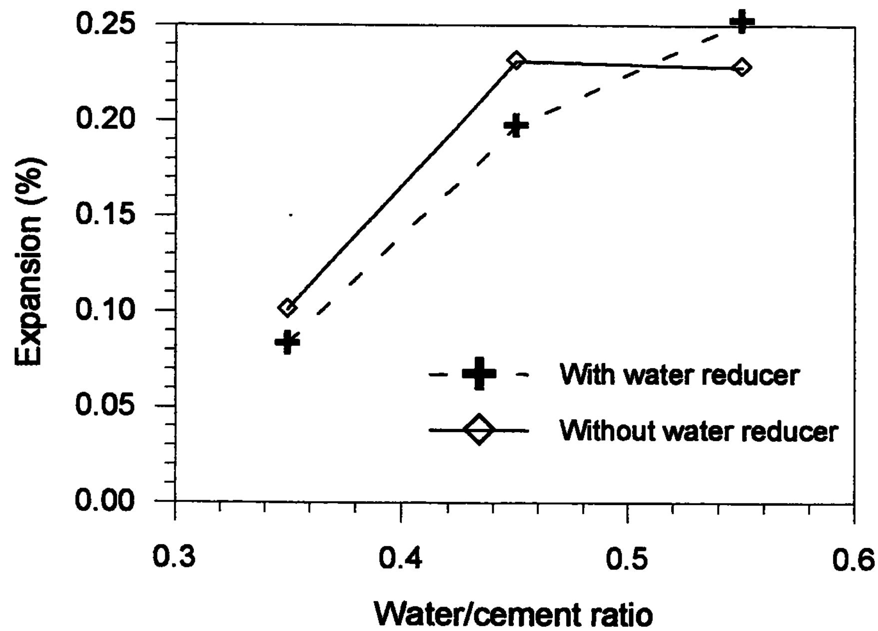
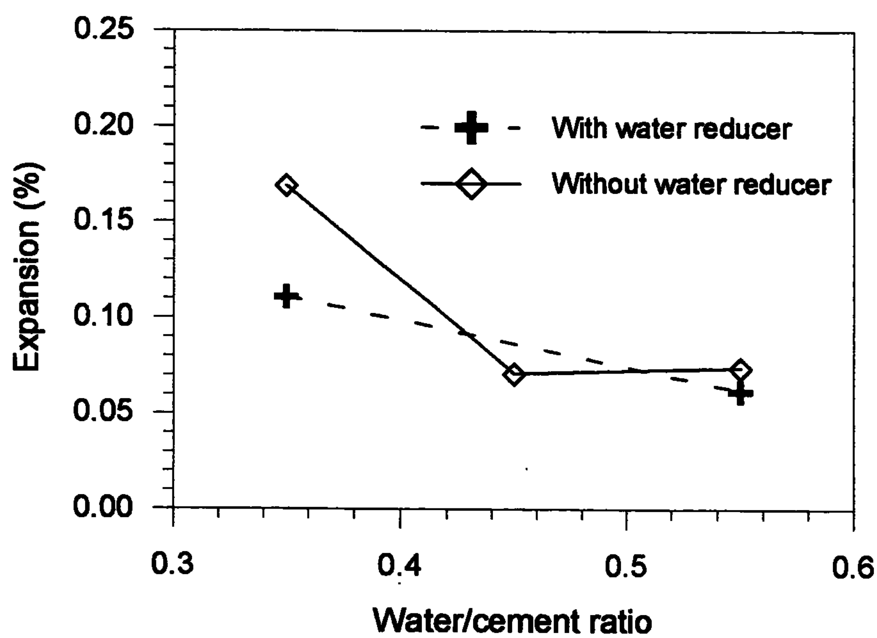


Fig. 10 Effects of air entrained agent (AEA) and water reducers (WR) on expansion

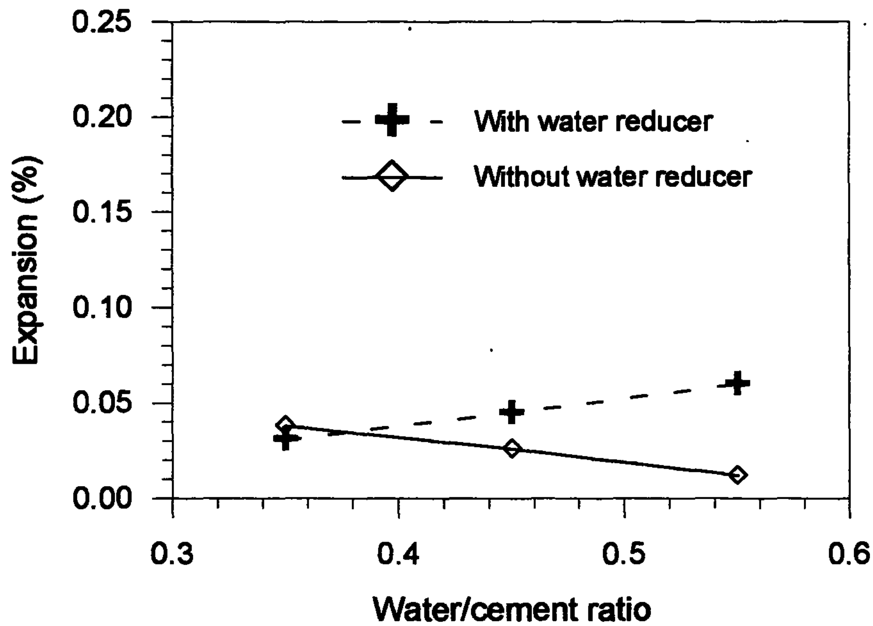


(a) Non air-entrained concrete

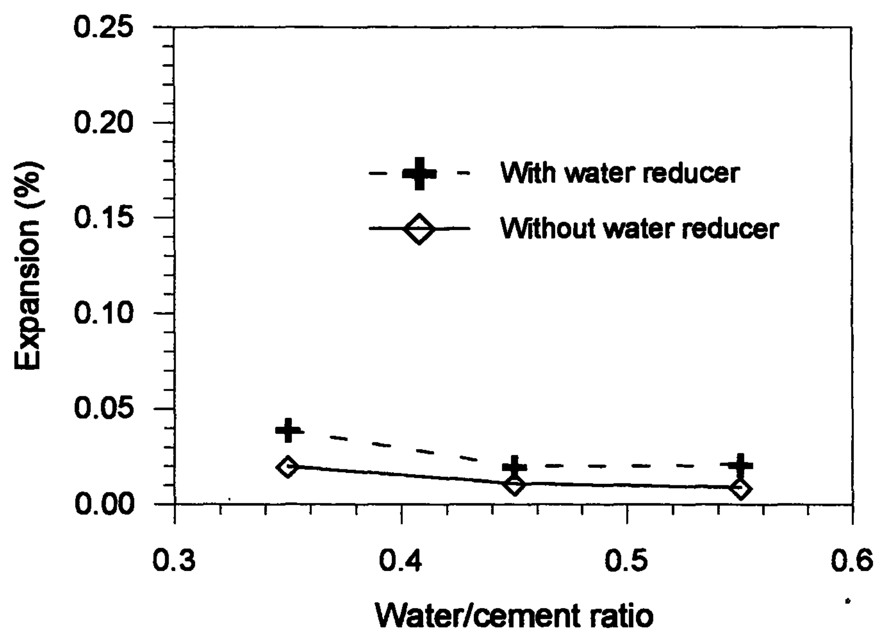


(b) Air-entrained concrete

Fig. 11 Effect of water/cement ratio on the expansion for mixes using cement 17 with K_2O = 0.92% and SO_3 = 4.1%



(a) Non air-entrained concrete



(b) Air-entrained concrete

Fig. 12 Effect of water/cement ratio on the expansion for mixes using cement 22 with K_2O = 0.32% and SO_3 = 1.6%