Center for By-Products Utilization

COAL-COMBUSTION BOTTOM ASH FOR REDUCING SHRINKAGE OF CONCRETE MADE WITH PORTLAND CEMENT AND SULFOALUMINATE CEMENT

By Tarun R. Naik, Rudolph N. Kraus, Yoon-moon Chun, and Samuel O. Nageotte

Report No. CBU-2006-22
REP-621
January 2007

For presentation and publication at the Jean Pera symposium during the Ninth CANMET/ACI International Conference on Recent Advances in Concrete Technology, Warsaw, Poland, May 2007.

Department of Civil Engineering and Mechanics
College of Engineering and Applied Science
THE UNIVERSITY OF WISCONSIN – MILWAUKEE

Coal-Combustion Bottom Ash for Reducing Shrinkage of Concrete Made With Portland Cement and Sulfoaluminate Cement

by Tarun R. Naik, Rudolph N. Kraus, Yoon-moon Chun, and Samuel O. Nageotte

Synopsis: This research was conducted to evaluate the potential of coal-combustion bottom ash for reducing the autogenous shrinkage of concrete. Compressive strength and splitting tensile strength of concrete were also evaluated. Bottom ashes were obtained from three sources, and the effect of replacement of natural sand or stone by bottom ash was assessed. Bottom ashes from two sources were used to replace approximately 75% of natural sand. Bottom ash from a third source was used to replace approximately 30% and 75% of natural coarse aggregate. Two groups of concrete mixtures were made using different blends of cementitious materials: (1) 70% portland cement + 30% Class C fly ash; and (2) 52% portland cement + 18% sulfoaluminate cement + 30% Class C fly ash. In both groups, the concrete mixtures containing bottom ash showed less autogenous shrinkage than the reference concrete mixtures made without bottom ash. By replacing 75% of either natural sand or natural stone with bottom ash, several concrete mixtures showed no autogenous shrinkage up to the age of at least 28 days. They maintained a slight lengthening, whereas their reference concrete showed autogenous shrinkage of 150 μm/m at 28 days. Thus, it was concluded that it is possible to develop concrete mixture proportions to achieve no or negligible autogenous shrinkage of concrete. Use of bottom ash reduced the compressive strength of concrete by 24 to 65% (average 45%) and the splitting tensile strength by 13 to 55% (average 32%). However, by revised mixture proportioning these strengths could be improved.

Keywords: autogenous shrinkage, bottom ash, compressive strength, splitting tensile strength, sulfoaluminate cement.

Tarun R. Naik, FACI, is a Research Professor and Academic Program Director of the UWM Center for By-Products Utilization (UWM-CBU) at the University of Wisconsin - Milwaukee. He is a member of ACI Committees 123, Research; 229, Controlled Low-Strength Materials (CLSM); and 232, Fly Ash and Natural Pozzolans in Concrete. He is Chairman of ACI Committee 555, Concrete with Recycled Materials. He is also a member of ACI Board Advisory Committee on Sustainable Development. He was Chairman of the ASCE Technical Committee on Emerging Materials (1995-2000).

ACI member Rudolph N. Kraus is Assistant Director of the UWM-CBU. He has directed numerous projects on the use of fly ash, bottom ash, used foundry sand, and wood ash in concrete, CLSM, and masonry units. Mr. Kraus has also directed research on self-consolidating concrete and the use of fibrous residuals from the pulp and paper industry in concrete.

Yoon-moon Chun is a Research Associate at the UWM-CBU. His research interests include the use of coal fly ash, coal bottom ash, and used foundry sand in concrete and masonry units; the use of fibrous residuals from pulp and paper mills in concrete; autogenous shrinkage of concrete; and self-consolidating concrete.

Samuel O. Nageotte was formerly a summer research student at the UWM-CBU. He received his bachelor's degree in Civil Engineering and Architecture from INSA (Institut National des Sciences Appliquees), Lyon, France.

INTRODUCTION

Innovative utilizations of calcium sulfoaluminate cement has been reported, including development of concrete with high early strength, design of self-leveling screed with limited curling, design of self-leveling topping mortar with low drying shrinkage, and glass-fiber-reinforced cement with high ductility and durability [1].

Coal-combustion bottom ash from a certain source has been successfully used as a surface material on service roads, park trails, and driveways [2]. This is due to the interlocking characteristic of angular particles of bottom ash. It has also been reported that bottom ash can be used as a pozzolanic material, by grinding it until the material retained on a 45-µm sieve is less than 5% [3]. It is also possible to produce lightweight concrete using bottom ash, and reduce the dead load of a structure.

This research was conducted to develop uses of coal-combustion bottom ash for reducing the autogenous shrinkage of concrete made with and without sulfoaluminate cement. Concrete mixtures were also tested for time of initial set (ASTM C 403), autogenous shrinkage, compressive strength (ASTM C 39), and splitting tensile strength (ASTM C 496).

MATERIALS

Two types of cement were used: ASTM Type I portland cement and sulfoaluminate cement. In addition ASTM Class C fly ash was used. Natural sand and crushed quartzite stone with a nominal maximum size of 19 mm were used. Bottom ashes were obtained from three electric utilities in Wisconsin, USA, and were designated as P4, WPS, and MGE.

Bottom ash

Bottom ash P4 -- In as-received condition, the bottom ash P4 was wet. It resembled dark rough sand with some coarse particles and few very large particles. Difference in appearance was not noticed between the different barrels of the bottom ash P4, as received. The bottom ash P4 was sieved while wet and only the portion passing a 4.75-mm sieve was used to replace part of natural sand in concrete mixtures.

Bottom ash WPS -- Except for its brown color, the bottom ash WPS was similar to the bottom ash P4 in appearance, gradation, and moisture content. Only the portion of the bottom ash WPS passing the 4.75-mm sieve was used to replace part of natural sand in concrete.

Bottom ash MGE -- In as-received condition, the size of the particles of the bottom ash MGE ranged from very fine to coarse, most of the particles being coarse. The bottom ash MGE was in dry condition. The presence of partially burnt paper and metal pieces was noticed. The appearance of the bottom ash MGE varied between barrels. The particles had soft round surfaces and were generally easily breakable. Only the portion retained on the 4.75-mm sieve was used to replace part of natural coarse aggregate in concrete.

Properties of the bottom ashes -- The portions of the bottom ashes P4 and WPS finer than the 4.75-mm sieve, and the portion of the bottom ash MGE coarser than the 4.75-mm sieve were tested for gradation by sieve analysis, moisture content, specific gravity, and absorption.

The test results for gradation of bottom ashes are shown in Figs. 1-4. Oven-dry samples and wet-samples of the bottom ash P4 showed approximately the same gradation (Figs. 1 and 2). The bottom ashes P4 and WPS finer than the 4.75-mm sieve met the gradation requirement for lightweight fine aggregate per ASTM Standard Specification for Lightweight Aggregates for Structural Concrete (C330) (Figs. 1-3). The gradation of the bottom ash MGE retained on the 4.75-mm sieve was approximately coincided with the upper limit of the gradation requirement for lightweight coarse aggregate per ASTM C 330 (Fig. 4.). Thus, the bottom ash MGE was treated as a lightweight coarse aggregate.

The test results for moisture content, specific gravity, and absorption of bottom ashes are shown in Table 1.

MIXTURE PROPORTIONS, RESULTS, AND DISCUSSIONS

Mixture proportions

The fine bottom ashes P4 and WPS were used in their as-received wet condition in making concrete mixtures. Since the as-received bottom ash MGE was dry, it was soaked in water for 24 hours and allowed to dry for one hour before it was used in concrete mixtures. The moisture content of the soaked bottom ash MGE was about 20%.

Tables 2 and 3 show the mixture proportions and fresh properties of concrete mixtures.

The bottom ashes P4 and WPS were used to replace 75% of natural sand by volume, and the bottom ash MGE was used to replace approximately 30% and 75% of natural coarse aggregate by volume. Due to the relatively low specific gravity of all bottom ashes, the percentage of replacement was calculated based on volume.

Two groups of concrete mixtures were made using different blends of cementitious materials: (1) 70% portland cement + 30% Class C fly ash; and (2) 52% portland cement + 18% sulfoaluminate cement + 30% Class C fly ash. To achieve a slump of 50 to 100 mm, high-range water-reducing admixture (HRWRA) was used in some of the mixtures containing fine bottom ash.

The mixtures I-W75 (Table 2) and S-P75 (Table 2) were produced without using HRWRA and had a relatively high water-cementitious ratio (W/Cm) of 0.54. The mixtures I-W75-2 and S-P75-2 were produced using HRWRA to achieve W/Cm of 0.47 and 0.46, respectively. The mixture I-M75 had a relatively high W/Cm of 0.56 (Table 2). The W/Cm of the rest of the concrete mixtures ranged from 0.43 and 0.48 (Tables 2 and 3).

Time of initial set

The time of initial set of the concrete mixtures without sulfoaluminate cement ranged from 8.5 to 11.5 hours (Table 2). In contract, the time of initial set of the concrete mixtures containing sulfoaluminate cement was much shorter, ranging from 1.8 to 3.5 hours (Table 2).

Autogenous shrinkage

Figures 4 and 5 show the test results for autogenous length change of concrete. The three sources of bottom ashes used in the mixtures reduced the autogenous shrinkage of concrete. This may be explained by the porosity of the bottom ash particles and the moisture contributed from them to the cementitious matrix during the curing and hydration process. Besides the high-quantity of water contained in the bottom ash, the porosity facilitates the suction and exit of the moisture.

The concrete mixtures I-W75, I-W75-2, and I-M75 did not show autogenous shrinkage (Fig. 4). They showed a slight expansion up to the age of at least 28 days. In addition, the mixtures I-M30 and I-P75 did not show autogenous shrinkage before the ages of approximately 10 and 17 days, respectively. Thus, it was possible to eliminate the early autogenous shrinkage of concrete by replacing either 75% of natural sand or 30 to 75% of natural stone with coal-combustion bottom ash.

The mixtures with sulfoaluminate cement showed higher shrinkage, because of the rapid hydration reaction. But still, the use of bottom ash reduced the autogenous shrinkage. The mixture S-P75-2 showed relatively small autogenous shrinkage.

Compressive strength and splitting tensile strength

Figures 7 to 10 show the test results for compressive strength and splitting tensile strength of concrete. Both the compressive strength and splitting tensile strength were reduced with the use of bottom ash. The reduction of compressive strength was more noticeable than the reduction of splitting tensile strength. The reduction in compressive strength was especially noticeable upon replacement of a portion of quartzite stone in portland cement concrete with the bottom ash MGE. However, by revised mixture proportioning these strengths could be improved.

On the surface of split cylinders, dark halos were observed around the particles of the coarse bottom ash MGE, showing the contribution of water to the cementitious matrix.

CONCLUSIONS

By replacing 75% of either natural sand or natural stone with coal-combustion bottom ash, three concrete mixtures showed no autogenous shrinkage up to the age of at least 28 days.

ACKNOWLEDGEMENTS

The authors would like to thank We Energies (Milwaukee, WI), Wisconsin Public Service Corporation (Green Bay, WI), and Madison Gas and Electric Company (Madison, WI) for supplying the bottom ashes used in this research. Samuel Nageotte's travel and living expenses for his summer research at the University of Wisconsin-Milwaukee (UWM) were provided by INSA (Institut National des Sciences Appliquees), Lyon, France.

The UWM Center for By-Products Utilization was established in 1988 with a generous grant from the Dairyland Power Cooperative, La Crosse, WI; Madison Gas and Electric Company, Madison, WI; National Minerals Corporation, St. Paul, MN; Northern States Power Company, Eau Claire, WI; We Energies, Milwaukee, WI; Wisconsin Power and Light Company, Madison, WI; and, Wisconsin Public Service Corporation, Green

Bay, WI. Their financial support and additional grant and support from Manitowoc Public Utilities, Manitowoc, WI, are gratefully acknowledged.

REFERENCES

1. J. Pera and J. Ambroise, "New Applications of Calcium Sulfoaluminate Cement," Cement and Concrete Research, Vol. 34, No. 4, pp. 671-676, April 2004.

2. B. W. Ramme, J. Lingle, and T. R. Naik, "Wisconsin Electric's Environmental Approach to Coal Combustion Products Utilization Including Fly Ash Lightweight Aggregate for Concrete," Published at the International Symposium on Construction Technology for Sustainable Developments in the Twenty-First Century, Hyderabad, India, February 1999.

3. C. Jaturapitakkul and R. Cheerarot, "Development of Bottom Ash as Pozzolanic Material," Journal of Materials in Civil Engineering, Vol. 15, No. 1, pp. 48-53, ASCE, January – February 2003.

Table 1—Properties of Aggregates

	Sand	Stone	Bottom Ash P4	Bottom Ash WPS	Bottom Ash MGE
As-received moisture content (%)	-	-	15	15	0
Bulk specific gravity at SSD	2.62	2.65	2.09	2.10	1.18 - 1.63
SSD Absorption (%)	1.4	0.4	13.6	15.8	17.5

Table 2—Mixture Proportions and Fresh Properties of Concrete without Sulfoaluminate Cement

Mixture Designation	I	I-repeat	I-P75	I-W75	I-W75-2	I-M30	I-M75
Bottom ash source	-	-	P4	WPS	WPS	MGE	MGE
Type I portland cement (kg/m^3)	243	243	244	230	230	251	211
Sulfoaluminate cement (kg/m^3)	0	0	0	0	0	0	0
Class C fly ash (kg/m^3)	104	104	105	99	101	108	92
Water (kg/m^3), W	157	157	166	178	154	155	169
Natural sand (kg/m^3)	859	859	207	197	198	913	816
P4 fine bottom ash (kg/m^3)	0	0	547	0	0	0	0
WPS fine bottom ash (kg/m^3)	0	0	0	520	535	0	0
Quartzite coarse aggregate (kg/m^3)	1040	1040	1000	940	990	680	260
MGE coarse bottom ash (kg/m^3)	0	0	0	0	0	199	428
HRWRA* (L/m^3)	0	0	0	0	3.9	0	0
W/Cm**	0.45	0.45	0.48	0.54	0.47	0.43	0.56
Slump (mm)	65	85	50	50	50	65	70
Air content (%)†	1.1	1.2	1.7	2.7	1.5	2.8	6.1
Density (kg/m^3)	2400	2400	2270	2160	2210	2310	1990
Time of initial set (hr)	8.5	N.Av.	9.0	9.7	11.5	9.0	10.8

* HRWRA: High-range water-reducing admixture
** Cm: Cement + fly ash.
† By ASTM C 231 pressure method.

Table 3—Mixture Proportions and Fresh Properties of Concrete Containing Sulfoaluminate Cement

Mixture Designation	S	S-P75	S-P75-2	S-W75	S-M30
Bottom ash source	-	P4	P4	WPS	MGE
Type I portland cement (kg/m^3)	173	180	185	172	192
Sulfoaluminate cement (kg/m^3)	58	58	60	59	64
Class C fly ash (kg/m^3)	100	104	107	101	109
Water (kg/m^3), W	150	184	163	151	157
Natural sand (kg/m^3)	862	202	210	200	942
P4 fine bottom ash (kg/m^3)	0	540	540	0	0
WPS fine bottom ash (kg/m^3)	0	0	0	539	0
Quartzite coarse aggregate (kg/m^3)	1050	960	960	1010	650
MGE coarse bottom ash (kg/m^3)	0	0	0	0	186
HRWRA* (L/m^3)	0	0	4.3	8.8	0
W/Cm**	0.45	0.54	0.46	0.46	0.43
Slump (mm)	70	50	55	100	50
Air content (%)†	1.5	1.8	2.9	2.8	2.8
Density (kg/m^3)	2390	2230	2230	2240	2290
Time of initial set (hr)	2.5	2.8	1.8	3.5	2.2

* HRWRA: High-range water-reducing admixture
** Cm: Cement + fly ash.
† By ASTM C 231 pressure method.

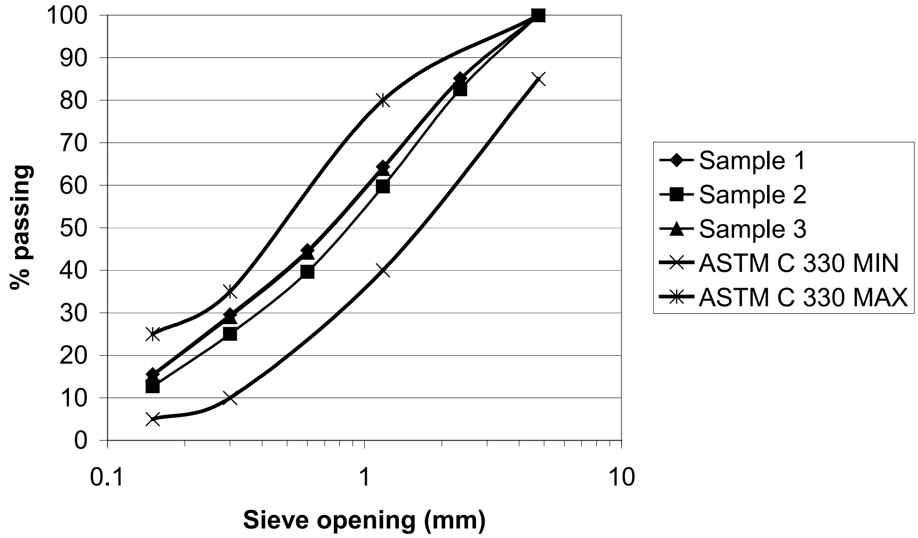

Fig. 1—Sieve analysis of oven-dry samples of the bottom ash P4

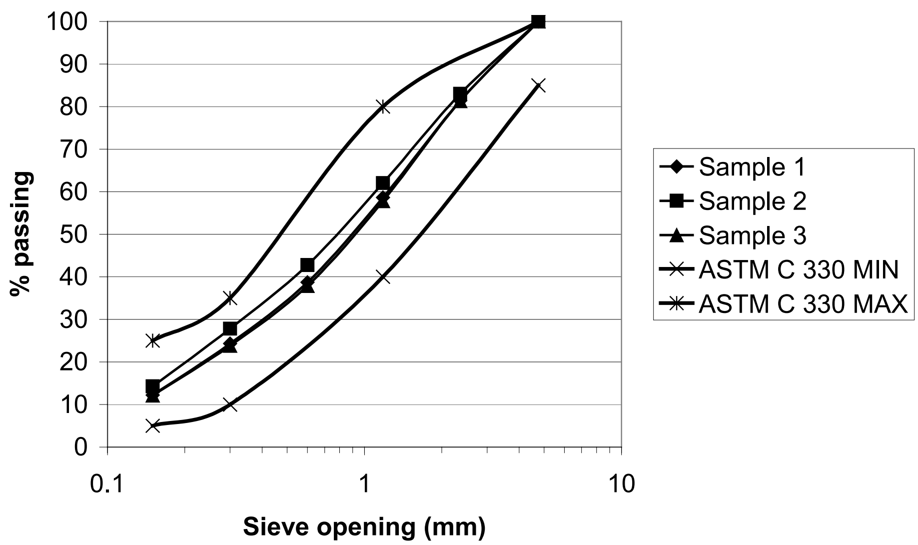

Fig. 2—Sieve analysis of wet samples of the bottom ash P4

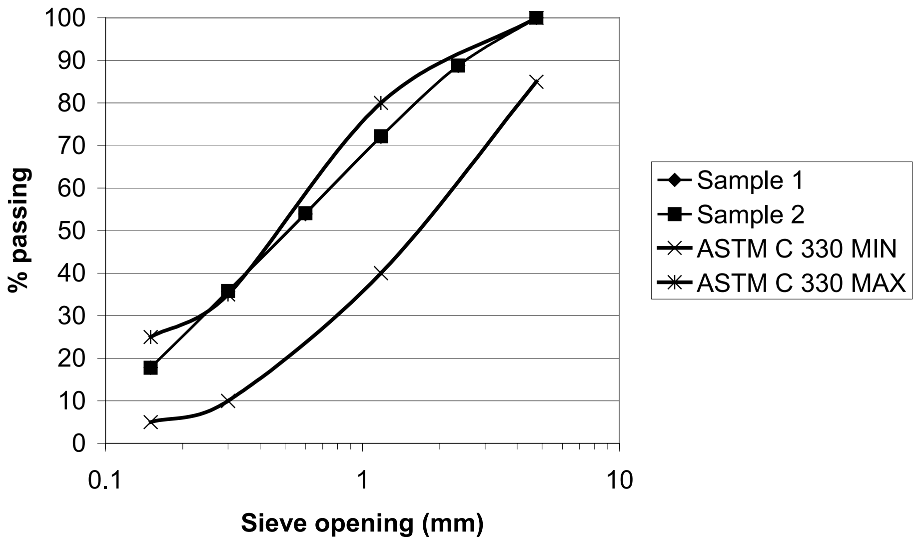

Fig. 3—Sieve analysis of wet samples of the bottom ash WPS

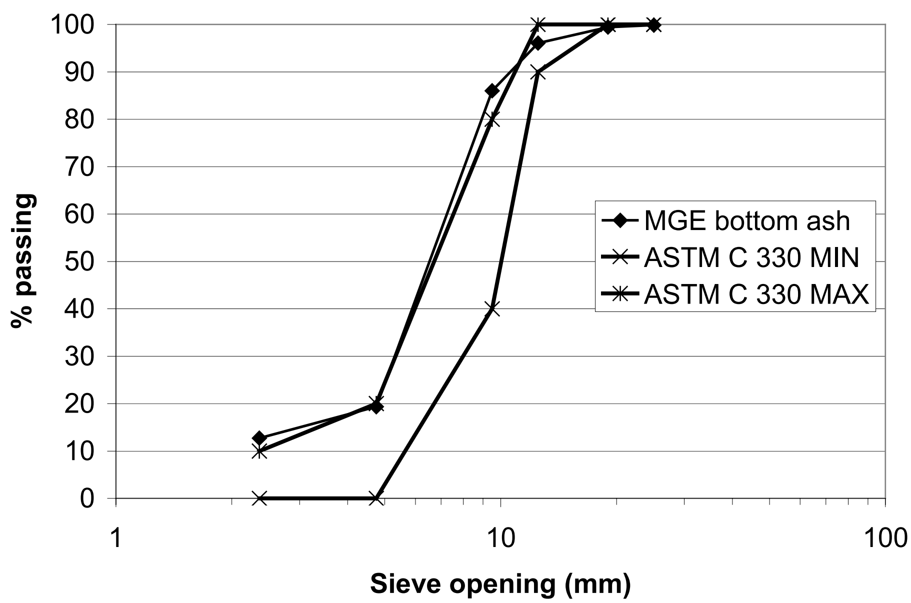

Fig. 4—Sieve analysis of wet samples of the bottom ash MGE

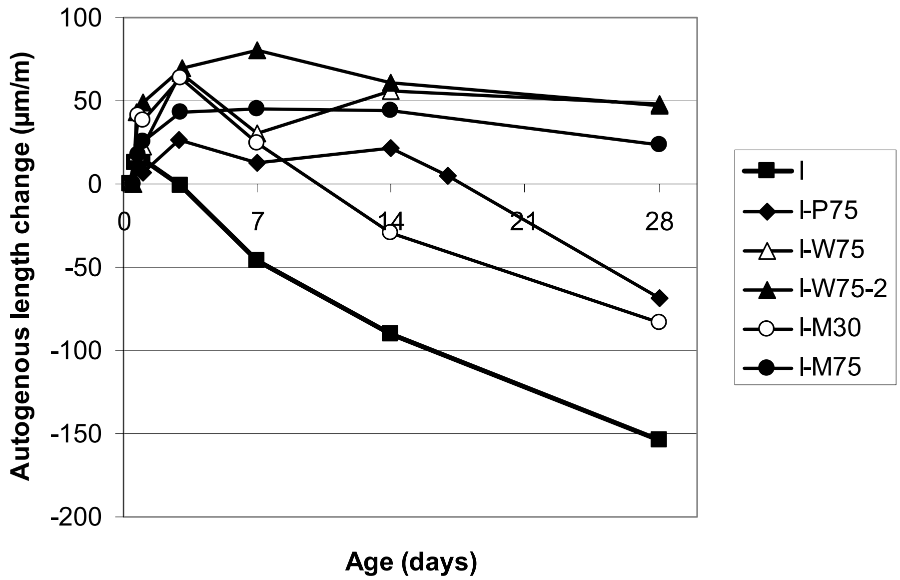

Fig. 5—Autogenous length change of concrete without sulfoaluminate cement

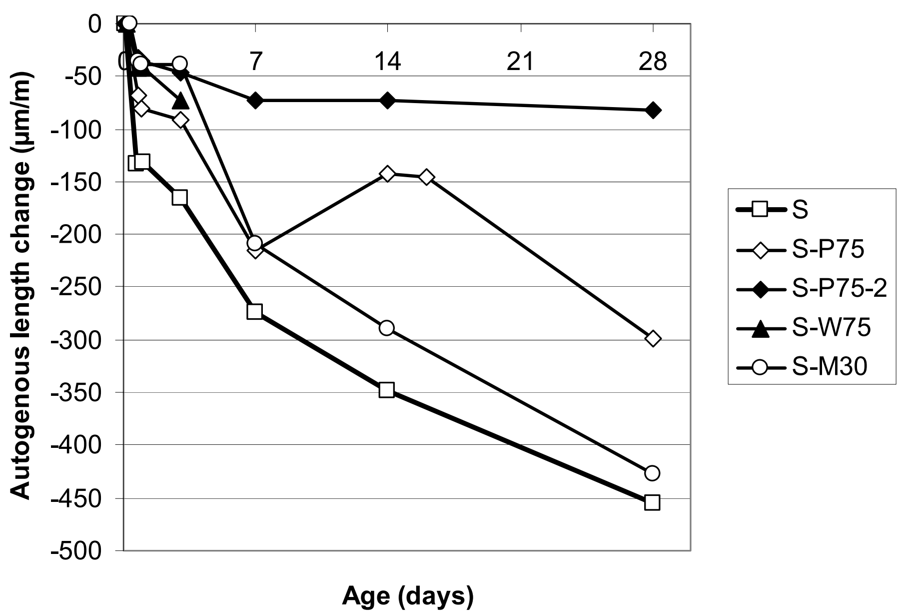

Fig. 6—Autogenous length change of concrete containing sulfoaluminate cement

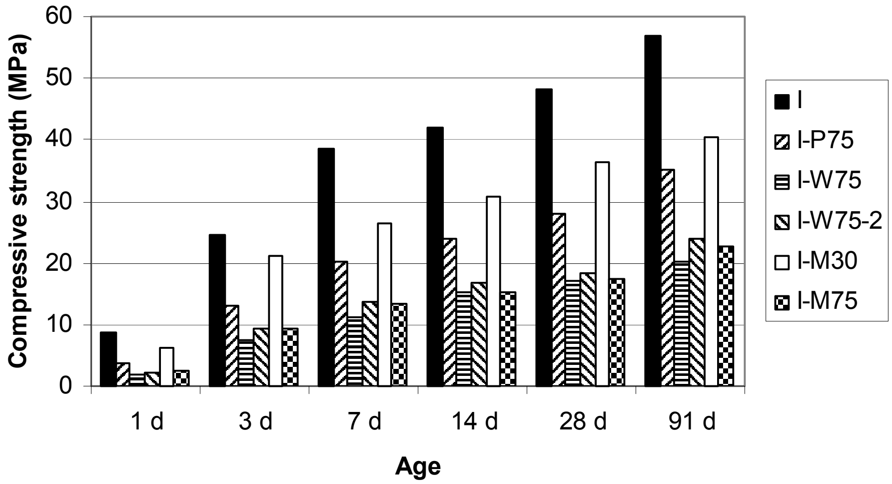

Fig. 7—Compressive strength of concrete without sulfoaluminate cement

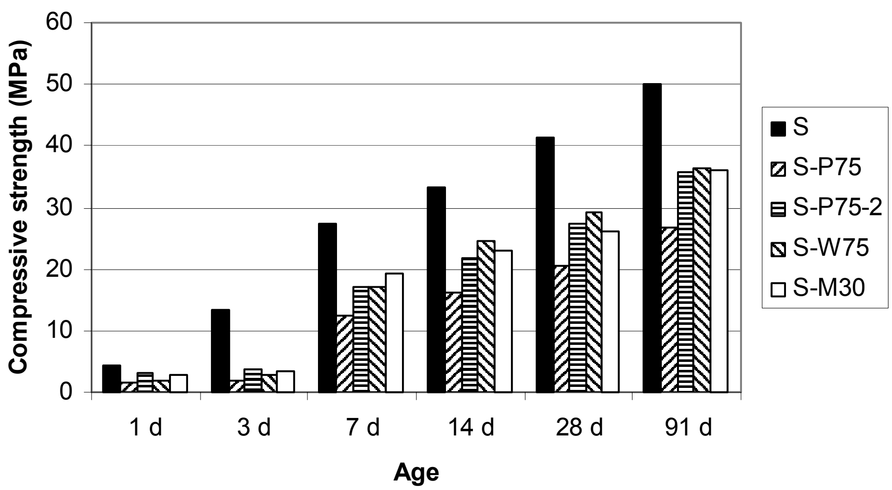

Fig. 8—Compressive strength of concrete containing sulfoaluminate cement

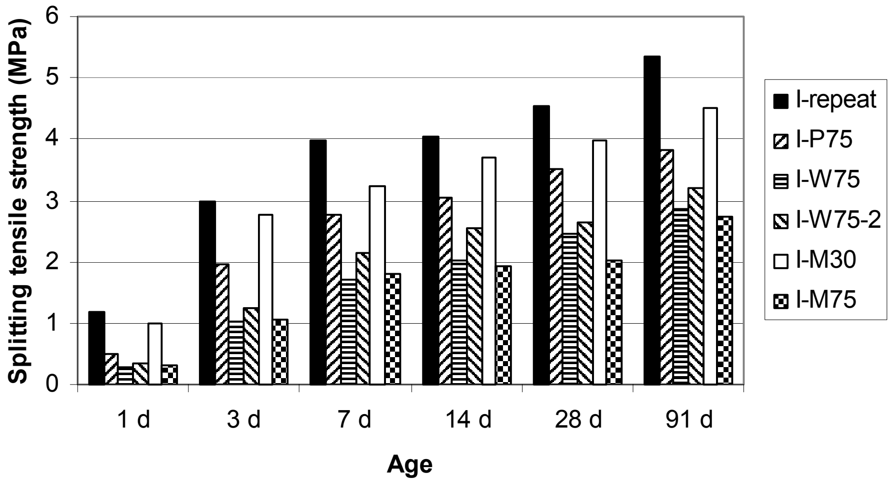

Fig. 9—Splitting tensile strength of concrete without sulfoaluminate cement

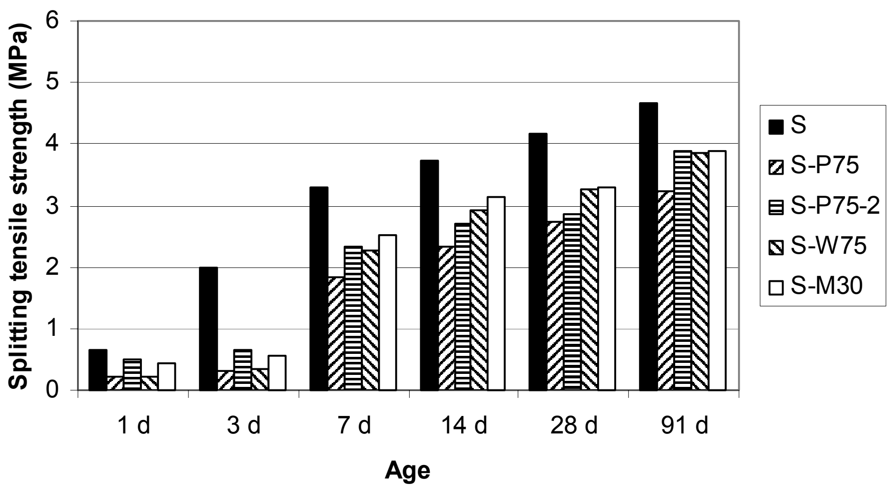

Fig. 10—Splitting tensile strength of concrete containing sulfoaluminate cement