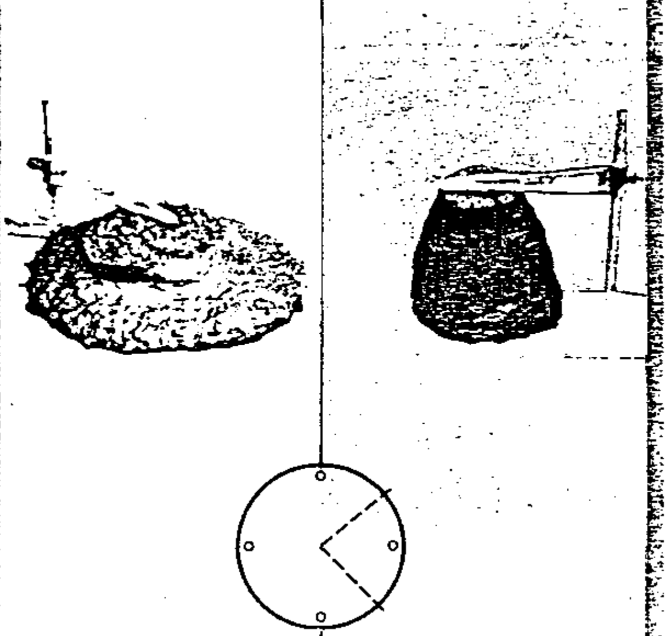
Developments in the Use of Super-plasticizers



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Superplasticized Shrinkage-Compensating Concrete

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Synopsis : Compressive strength and restrained expansion tests were carried out on concretes containing naphthalene sulphonic formaldehyde type superplasticizer and an expansive agent based on processed lime.

At constant expansive agent content, the higher the early strength (1 day) the higher was the restrained expansion. Therefore, if the superplasticizer is used to increase the early strength by reducing the water/cement ratio, it is possible to reduce the content of the expansive agent to obtain the same degree of expansion.

On the other hand, if the superplasticizer is used to reduce both water and cement, and therefore the drying shrinkage, less expansive agent would be required for shrinkage compensation purposes.

The results of the present work indicate that the combination of a superplasticizer and an expansive agent may be more advantageous than the use of expansive agent alone.

Keywords: coarse aggregates; compressive strength; drying shrinkage; expanding agents; expansion; naphthalene compounds; plasticizers; portland cements; shrinkage-compensating concretes; strength; water-cement ratio.

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INTRODUCTION

It is generally known that high water/cement ratio and low aggregate/cement ratio cause an increase in drying shrinkage of concrete. When mixing water and cement content are reduced in an effort to reduce drying shrinkage, the mixture becomes difficult to place and compact. Therefore when a superplasticizer is added to achieve ease of placeability in such concrete mixtures, the drying shrinkage is reduced (1,2) but is not completely eliminated. For complete elimination of drying shrinkage, the use of shrinkage-compensating concrete is necessary.

Shrinkage-compensating concrete is constituted so that the concrete increases in volume during moist curing. This volume increase must be properly restrained by reinforcing steel of external confinements and must occur after the concrete has hardened (3). When the concrete expands, the reinforcing steel bars are put in tension, whereas compressive stresses are induced in the concrete. Subsequent drying shrinkage reduces these stresses but a residual compression remains in the concrete, thereby eliminating the tendences to crack on drying (3). Fig. 1 schematically shows the typical length change history of an ordinary concrete and a shrinkage-compensating one.

In the United States expansive cements are used to produce shrinkage-compensating concretes, whereas in Italy, as well as in Japan, suitable amounts of expansive agents are used as admixtures at job site or prefabrication plant at the time of mixing concrete.

There are substantially two types of expansive agents. The first one is based on calcium sulfoaluminate or calcium aluminate which reacts with gypsum and water, producing ettringite. The second type is based on calcium oxide which reacting with water is transformed in calcium hydroxide. Both ettringite and calcium hydroxide formation causes an expansive phenomenon. The clinkering temperature of an expansive agent, the particle size distribution and the presence of coatings on the main expansive compounds can be used to regulate the rate of expansion. Expansion must occur when the concrete is in the hardened state in order that the restrained expansion can induce a compressive stress in the concrete and a tensile stress in the reinforcement. Therefore expansion must occur after the setting and during hardening of concrete.

Any expansive agent or cement can cause a volume increase if concrete is kept under water or moisture-proof covers. In general, the reaction causing the expansion requires a minimum of 7 days of moist curing (Fig. 2). A more rapid expansion occurs when the early compressive strength of an ordinary concrete is too low, i.e. the bond between concrete and steel is insufficient to induce a tensile stress in the reinforcement and a compressive stress in the concrete.

The main purpose of the present work was to examine whether in the presence of a superplasticizer (causing a reduction in the water/cement ratio) the increase in the early compressive strength obtained would enable a reduction in the amount of expansive agent needed to produce a given degree of restrained expansion.

EXPERIMENTAL

Materials

Type I and III Portland cements were used. Graded gravel of 19 mm maximum size was used as coarse aggregate. The fine aggregate was natural sand. A naphthalene sulphonic formaldehyde condensed (NSFC) polymer based superplasticizer* was generally used except in one case (Table IV) where a retarding type of (NSFC)

* Rheobuild 878

superplasticizer** was used. A special clinker rich in free lime *** was used as a rapid expansive agent so that the ASTM expansion (ASTM C 878-78) is completed in about one day (Fig. 2).

Concrete Mixtures

The mixture proportions and the characteristics (slump, compressive strength, shrinkage and restrained expansion) are reported in Table I to Table IV. Slump, shrinkage and restrained expansion were determined using the ASTM test methods, whereas compression cubes (100 mm) were tested according to Italian UNI 6137-72 test method. In some cases the bond of concrete to steel was determined according to RILEM-FIP-CEB pull-out test.

RESULTS AND DISCUSSION

Table I shows the influence of different dosages of superplasticizer on the characteristics of concretes containing the same amount of expansive agent (about 8 % by weight of cement). All the mixes were prepared at the same workability (slump = 100 mm) and with the same cement content (about 350 kg/m^3). However, because of the decrease in the water/cement ratio both the 1 day and the 28 day compressive strengths increase by increasing the dosage of superplasticizer. The shrinkage at 2 years decreases by increasing the superplasticizer content because of the lower water/cement ratio and, to a lower extent, the slightly higher aggregate/cement ratio. On the other hand, the ASTM C 878-78 restrained expansion increases by increasing the amount of superplasticizer and only by using 4.26 kg/m^3 of superplasticizer (about 1.2 % by weight of cement) the restrained expansion (580 . 10^{-6}) is slightly higher than the shrinkage at 2 years (460 . 10^{-6}). The increase in the restrained expansion caused by the addition of the superplasticizer is only due to the increase in the compressive strength and therefore in the steel-concrete bond.

In order to confirm the effect of the superplasticizer on the restrained expansion, compressive strength, steel-concrete bond and expansion measurements were simultaneously carried out

** Rheobuild 561

*** Stabilmac

after the setting time (about 6 hours) and during the initial hardening for mix A and D of Table I (Fig. 3). It seems that the more rapid the strength development, the better the concrete-steel bond and therefore the restrained expansion of the specimen.

Table II shows the influence of superplasticizer on ordinary and shrinkage-compensating concretes having the same slump (150 mm) and the same water/cement ratio (about 0.60), and therefore the same compressive strength (6 MPa at 1 day and about 32 MPa at 28 days). Because of the presence of superplasticizer, a reduction in the cement content and an increase in the aggregate/cement ratio were achieved. This causes a reduction in the shrinkage at 2 years from about 800 . 10^{-6} to about 330 . 10^{-6} for the superplasticized concrete. Therefore the amount of expansive agent required to compensate the 2 years shrinkage went down from 78 kg/m^3 (about 23 % by weight of cement) for the concrete without superplasticizer to 38 kg/m^3 (about 15 % by weight of cement) for the superplasticized concrete.

Table III shows the influence of superplasticizer when used to reduce the water/cement ratio from about 0.60 to 0.45. All the mixes were of the same slump (150 mm) and approximately the same cement content (about 340 kg/m^3). Because of the significant reduction in the water/cement ratio and, to a less extent, the slight increase in the aggregate/cement ratio, superplasticized concrete showed lower shrinkage at 2 years. Due to the presence of superplasticizer, the amount of expansive agent needed to compensate for this shrinkage decreased from 78 to 27 kg/m^3, corresponding to only 8 % by weight of cement. Thus, one can see that when the superplasticizer was used to reduce the water/cement ratio (Table III) the amount of expansive agent (27 kg/m^3) required to compensate the shrinkage was lower than that of mixture D of Table II (38 kg/m^3) where the superplasticizer was used to reduce the cement content, even though the shrinkage was somewhat higher (460 . 10^{-6} instead of 320 . 10^{-6}). This is due to the fact that the 1 day compressive strength for mixture D of Table III (10 MPa) was higher than that of mixture D of Table II (6 MPa). All the other properties of the hardened concrete were, of course, better when the superplasticizer was used to reduce the water/cement ratio (Table III), rather than reducing the cement content (Table II).

In Table IV the influence of the type of superplasticizer is shown. A normal and a retarding superplasticizer with different slump loss were used. The retarding superplasticizer might be used together with an expansive agent when a shrinkage-compensating concrete must be transported for long distances particularly in hot climates. The water/cement ratio for both the superplasticized concretes was 0.45, so that the same shrinkage at 2 years ($450 \cdot 10^{-6}$) and approximately the same compressive strength at 28 days were obtained. However, when the retarding superplasticizer was used the early compressive strength (1 day) was lower (8 MPa) than that obtained in the presence of the normal superplasticizer (10 MPa). Consequently, a greater amount (34 instead of 27 kg/m^3) of expansive agent was required to obtain approximately the same restrained expansion ($470 \cdot 10^{-6}$).

Thus, once again it is confirmed that, in order to obtain a given restrained expansion, a lower amount of expansive agent was required when the early compressive strength (therefore the steel-concrete bond) was better for a lower water/cement ratio (Table III). In other words, the higher the early compressive strength, the higher was the restrained expansion for a given amount of expansive agent. This is summarized in Fig. 4 where the restrained expansion is shown as a function of the content of expansive agent for concretes with 1 day compressive strength changing from a minimum of 3-6 MPa to a maximum of 29-39 MPa. For instance, for the same content of expansive agent of 30 kg/m^3 the restrained expansions were $350 \cdot 10^{-6}$ and $950 \cdot 10^{-6}$, respectively, for concretes having the 1 day compressive strength 7 - 8 MPa and 22 - 28 MPa.

CONCLUSIONS

The use of superplasticizer, through decrease of water/cement ratio and increase in the early compressive strength, allows the production of shrinkage-compensating concretes containing lower amounts of expansive agent. When in combination with the expansive agent the superplasticizer was used for reducing the water/cement ratio, all the characteristics of the superplasticized shrinkage-compensating concrete, such as strength, steel-concrete bond etc. were superior to those of the shrinkage-compensating concretes without the superplasticizer.

REFERENCES

1. Lane, R.O. and Best, J.F., "Laboratory Studies on the Effects of Superplasticizers on the Engineering Properties of Plain and Fly-Ash Concrete", ACI SP-62, "Superplasticizers in Concrete", 1979, pp. 193-207.

2. Collepardi, M., Corradi, M., Valente, M., "Low-Slump-Loss Superplasticized Concrete", Proceedings, Transportation Research Record, Symposium on Superplasticizers in Concrete, National Academy of Sciences, Whashington D.C., 1979, pp. 7-12.

3. ACI Commitee 223, "Recommended Practice for the Use of Shrinkage-Compensating Concrete", J. Am. Concr. Inst., V. 73, No. 6, June 1976, pp. 319-339.

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Table I - Mix proportions and characteristics of concretes containing the same amount of expansive agent and different dosages of superplasticizer.

CONCRETE MIXTURE	A	B	C	D
SLUMP (mm)	100	100	100	100
TYPE III CEMENT CONTENT (Kg/m³)	350	352	353	355
WATER CONTENT (Kg/m³)	200	187	177	153
SUPERPLASTICIZER (Kg/m³) (% BY WEIGHT OF CEMENT)	—	1.06 (0.3%)	2.12 (0.6%)	4.26 (1.2%)
WATER / CEMENT	0.57	0.53	0.50	0.43
AGGREGATE / CEMENT	4.9	5.1	5.2	5.3
COMPRESSIVE STRENGTH (MPa) 1 DAY	7.5	9	12	15
COMPRESSIVE STRENGTH (MPa) 28 DAYS	40	46	50	60
SHRINKAGE AT 2 YEARS (10^{-6})	830	720	630	460
ASTM RESTRAINED EXPANSION (10^{-6})	350	450	530	580
EXPANSIVE AGENT (Kg/m³) (% BY WEIGHT OF CEMENT)	28 (8%)	28 (8%)	28 (8%)	28 (8%)

Table II - Mix proportions and characteristics of plain (A), shrinkage-compensating (B), superplasticized (C) and superplasticized shrinkage-compensating (D) concretes.

CONCRETE MIXTURE	A	B	C	D
SLUMP (mm)	150	150	150	150
TYPE I CEMENT CONTENT (Kg/m³)	342	333	257	253
WATER CONTENT (Kg/m³)	205	200	154	152
SUPERPLASTICIZER (Kg/m³) (% BY WEIGHT OF CEMENT)	—	—	3.08 (1.2%)	3.04 (1.2%)
WATER / CEMENT	0.59	0.60	0.61	0.60
AGGREGATE / CEMENT	5.2	5.2	7.7	7.7
COMPRESSIVE STRENGTH (MPa) 1 DAY	6	6	6	6
COMPRESSIVE STRENGTH (MPa) 28 DAYS	32	31	33	32
SHRINKAGE AT 2 YEARS (10^{-6})	800	790	330	320
ASTM RESTRAINED EXPANSION (10^{-6})	—	840	—	340
EXPANSIVE AGENT (Kg/m³) (% BY WEIGHT OF CEMENT)	—	78 (23%)	—	38 (15%)

Table III - Mix proportions and characteristics of plain (A), shrinkage-compensating (B), superplasticized (C) and superplasticized shrinkage-compensating (D) concretes.

CONCRETE MIXTURE	A	B	C	D
SLUMP (mm)	150	150	150	150
TYPE I CEMENT CONTENT (kg/m³)	342	333	342	339
WATER CONTENT (kg/m³)	205	200	151	153
SUPERPLASTICIZER (kg/m³) (% BY WEIGHT OF CEMENT)	—	—	4.10 (1.2%)	4.07 (1.2%)
WATER / CEMENT	0.59	0.60	0.45	0.45
AGGREGATE / CEMENT	5.2	5.2	5.6	5.6
COMPRESSIVE 1 DAY STRENGTH (MPa) 28 DAYS	6 32	6 31	10 48	10 47
SHRINKAGE AT 2 YEARS (10^{-6})	800	790	460	460
ASTM RESTRAINED EXPANSION (10^{-6})	—	840	—	480
EXPANSIVE AGENT (kg/m³) (% BY WEIGHT OF CEMENT)	—	78 (23%)	—	27 (8%)

Table IV - Mix proportions and characteristics of shrinkage-compensating (A) and superplasticized shrinkage-compensating (B and C) concretes.

CONCRETE MIXTURE	A	B	C
SLUMP (mm) AFTER MIXING AFTER 1 HOUR	150 100	150 50	150 120
TYPE I CEMENT CONTENT (kg/m³)	333	339	338
WATER CONTENT (kg/m³)	200	153	152
SUPERPLASTICIZER TYPE	—	ACCEL.	RETARD.
SUPERPLASTICIZER CONTENT (kg/m³) (% BY WEIGHT OF CEMENT)	—	4.07 (1.2%)	3.38 (1.0%)
WATER / CEMENT	0.60	0.45	0.45
AGGREGATE / CEMENT	5.2	5.6	5.6
COMPRESSIVE 1 DAY STRENGTH (MPa) 28 DAYS	6 31	10 47	8 48
SHRINKAGE AT 2 YEARS (10^{-6})	790	460	450
ASTM RESTRAINED EXPANSION (10^{-6})	840	480	470
EXPANSIVE AGENT (kg/m³) (% BY WEIGHT OF CEMENT)	78 (23%)	27 (8%)	34 (10%)

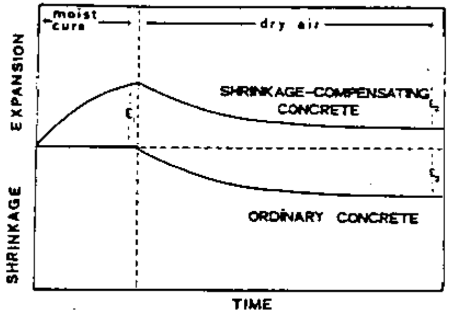

Fig. 1--Length change or ordinary and shrinkage-compensating concrete

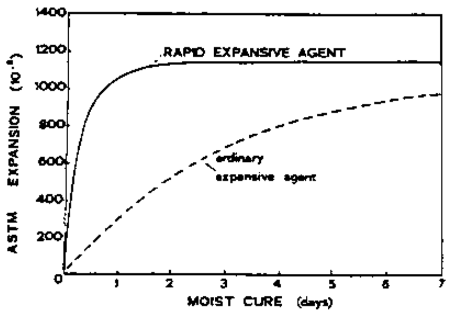

Fig. 2--Expansion as a function of moist cure for rapid and ordinary expansive agent

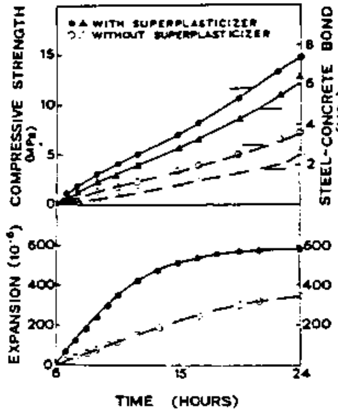

Fig. 3--Concrete compressive strength, steel-concrete bond and restrained expansion as a function of time (after setting) for shrinkage-compensating concrete without and with superplasticizer (Mix A and D of Table I)

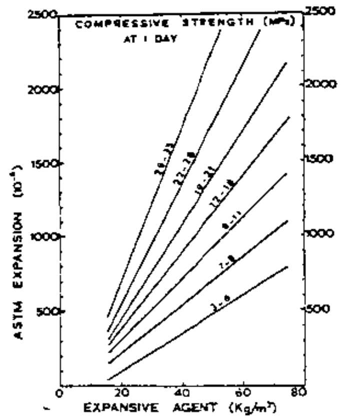

Fig. 4--ASTM restrained expansion at 1 day as a function of expansive agent content for concretes with different 1 day compressive strength