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THE INFLUENCE OF POLYPROPYLENE FIBERS AND AGGREGATE GRADING ON THE PROPERTIES OF DRY-MIX SHOTCRETE

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ABSTRACT

This paper presents the results of tests performed to evaluate the influence of the use of polypropylene fibers, of the grading of the fine aggregate, and of the coarse to fine aggregate proportion on various properties of dry-mix shotcrete. These results indicate that the use of polypropylene fibers (2 or 4 kg/m^3) does not significantly modify the mechanical strength, the drying shrinkage, and the frost/salt durability of dry-mix shotcrete. An increase in the proportion of coarse aggregate, and an increase of the fineness modulus of the fine aggregate, however, appears to improve the frost/salt durability.

Introduction

Many papers have been published in the last thirty years on the properties of both dry and wet-mix shotcrete [1, 2, 3]. The data presented in these papers, however, are generally based on the results from a few test mixtures or from test panels prepared during construction. It is thus difficult to compare the results coming from these papers to obtain precise information on the influence of certain parameters, because the equipment used in the various projects was different, the exposure conditions were different, the curing regimes were different, etc.

The use of polypropylene fibers in dry-mix shotcrete is usually not recommended, since it seems that a very significant proportion of the fibers do not reach the receiving surface [4]. Some organizations, however, require the use of polypropylene fibers in dry-mix shotcrete, and there is no clear information in the technical literature on the properties of dry-mix shotcrete containing polypropylene fibers. The research described in this paper was performed to obtain information on the influence of the use of these fibers, as well as on the influence of the grading of the fine aggregate and of the coarse to fine aggregate proportion, on the strength and durability of dry-mix shotcretes. Such information should be useful to engineers that have to select the composition of dry-mix shotcrete for the construction or repair of structures.

Materials, mixtures, and operating procedures

To evaluate the influence of the use of polypropylene fibers, six different shotcrete mixtures were made using two different binders: a Canadian type 30 cement (ASTM type III), and a Canadian type 10 cement (ASTM type I) with 7% silica fume. With each binder, one mixture was made without fibers, a second one with 2 kg/m^3 of polypropylene fibers, and a third one with 4 kg/m^3. Table 1 presents the composition and fineness of the cement. The coarse aggregate was a 10 mm nominal size crushed hard dolomite with a 24 hour absorption of 1,76%, and the fine aggregate, a granitic sand with a fineness modulus of 2,37. This modulus is defined in the Canadian Standard A23.1 : it is obtained by dividing by 100 the sum of the cumulative percentages retained on the normalized sieves (5 mm; 2,5 mm; 1,25 mm; 630 μm; 315 μm and 160 μm). A low value of the modulus therefore indicates a fine sand, and a higher value a coarser one. The composition of the six shotcrete mixtures is presented in Table 2. In this Table, the cement, silica fume, fine aggregate, and coarse aggregate content are given as a percentage of the total mass of dry materials. The quantity of fibers (in kg/m^3) is the nominal quantity, i.e. it was calculated on the basis of the amount of fibers added to the dry materials.

TABLE 1 - Cement characteristics.

	Type 10	Type 30
Blaine (m^2/kg)	378	517
C_3S	42%	58%
C_2S	28%	16%
C_3A	9,2%	8,9%
C_4AF	8,5%	4,7%
Loss on ignition	1,4%	1,3%

TABLE 2: Composition of the mixtures

Mixes	Cement type(1)	Sand fineness modulus	Binder(2) content (%)	Silica fume(3) (%)	Fine aggregate content(2) (%)	Coarse aggregate content(2) (%)	Polypropylene fibers (kg/m^3)
CM1	30	2,37	22	–	67	11	–
CM1-2f	30	2,37	22	–	68	10	2
CM1-4f	30	2,37	22	–	68	10	4
SM1(4)	10	2,37	23	7	68	11	–
SM1-2f	10	2,37	23	7	66	12	2
SM1-4f	10	2,37	23	7	69	10	4
SM0	10	2,37	22	8	80	–	–
SM1(4)	10	2,37	23	7	68	11	–
SM2	10	2,37	23	7	58	20	–
SM3	10	2,37	23	7	49	30	–
SF0	10	2,23	23	7	79	–	–
SF1	10	2,23	20	7	62	19	–
SG0	10	3,17	22	7	79	–	–
SG1	10	3,17	22	7	67	13	–

* All mixtures contained an air entraining admixture at a dosage of 20 ml/l of water used for shooting

(1) 10: Canadian type 10
30: Canadian type 30

(2) Percentage of the total mass of dry materials

(3) Percentage of total mass of binder (silica fume + cement)

(4) Same mixture

To evaluate the influence of the grading of the fine aggregate and of the coarse to fine aggregate proportion, seven additional shotcrete mixtures were prepared with the same type 10 cement and silica fume : three with the same fine aggregate as in the previous series and various amounts of the same coarse aggregate (from 0% to 30% of the total mass of dry materials), two with a finer sand (with 0% and 10% of coarse aggregate respectively), and two with a coarser one (also with 0% and 10% of coarse aggregate). The composition of these mixtures is also presented in Table 2. The gradings of the three fine aggregates are given in Table 3.

In Table 2 and in Table 4 where the test results are presented, all mixtures are identified in the following way : the first letter represents the type of binder (C for the type 30 cement, and S for the type 10 cement with silica fume), the second letter, the fineness of the sand (F for the finer sand, M for the medium one, and C for the coarser one), and the first digit indicates the amount of coarse aggregate (0 for none, 1 for 10%, 2 for 20%, and 3 for 30%). The code name of the 4 mixtures which contain polypropylene fibers are followed by -2f (2 kg/m^3 of fibers) or -4f (4 kg/m^3).

TABLE 3 - Grading of the fine aggregates

Sieve size, U.S. standard square mesh	F (% passing)	M (% passing)	C (% passing)
3/8" (9,52 mm)	–	100	100
4 (4,76 mm)	100	96,5	87
8 (2,38 mm)	99	89,5	73
16 (1,19 mm)	84	77,5	57
30 (0,59 mm)	57	55	36
50 (0,297 mm)	23	21,5	14
100 (0,149 mm)	7	7	6
200 (0,074 mm)	1	1	1
Fineness modulus	2,23	2,37	3,17

All dry materials were pre-bagged. An air-entraining admixture (a synthetic detergent) was utilized at a dosage of 20 ml/l of water. This dosage was selected on the basis of previous tests [5]. The admixture was diluted into the water used for shooting, this water being placed in a tank working under pressure. Typical dry-mix shotcrete equipment was used for shooting. The tests performed to determine the amount of fibers in the in-place shotcrete, as well as other tests performed on the fresh shotcretes, are described elsewhere [6].

For each mixture, a minimum of three test panels were made, the surface to be tested for the deicer salt scaling resistance being finished with a wooden trowel. All panels were cured under wet burlap for 7 days.

The cores and specimens required for the different tests (compressive strength (ASTM C42), drying shrinkage (ASTM C157), chloride ion permeability (AASHTO T277-831), characteristics of the air void system (ASTM C457), volume of permeable voids (ASTM C642), and deicer salt scaling resistance (ASTM C672)) were simply taken from the test panels. The compressive strength tests were performed on 75 mm in diameter and 125 mm in length cores. These were drilled a few days after the end of curing, stored under laboratory conditions, and tested 21 days after the end of curing. The volume of permeable voids and the chloride ion permeability were measured on specimens taken from the panels more than one month after the end of curing. The specimens for the drying shrinkage measurements were sawed from the panels during the curing period, and stored in lime water until the tests (at age 7 days). The scaling tests were carried out on slabs sawed approximately 21 days after the end of the curing period, and stored under laboratory conditions for an additional period of three weeks.

Test results

The test results for all mixtures are presented in Table 4 which gives the compressive strength (MPa), the drying shrinkage (μm/m), the chloride ion permeability (C), the spherical air void content of the hardened concrete (%), the total air void content of the hardened concrete (%), the air void spacing factor (μm), the volume of permeable voids (%), and the amount of scaling residues (kg/m^2) after 50 cycles of freezing and thawing in the presence of a deicer salt solution. Although a certain number of flexural strength and toughness tests (ASTM C1018) were performed, the results are not shown, since the polypropylene fibers, as expected, were not found to add any toughness to these shotcretes.

TABLE 4 - Tests on hardened shotcrete (influence of polypropylene fibers)

Mixes	Permeable voids (%)	Drying shrinkage(1) (μm/m)	Chloride permeability (C)	Air content (bubbles only)(2) (%)	Total air content (%)	Spacing factor (μm)	Compressive strength (MPa)	Scaling residues (kg/m^2)
CM1	34	761	4775	3,5	8,5	259	14,3	0,4
CM1-2f	32	928	12750	2,8	5,2	243	17,6	0,2
CM1-4f	30	810	8019	2,9	5,6	246	18,2	0,1
SM1	30	1147	1956	3,2	6,3	178	18,0	1,2
SM1-2f	39	821	963	3,7	6,4	235	16,7	2,5
SM1-4f	30	782	1220	2,8	5,3	235	19,7	2,2
SM0	37	878	2051	3,5	6,9	180	17,4	4,1
SM1	30	1147	1956	3,2	6,3	178	18,0	1,2
SM2	32	841	967	2,7	6,7	170	15,3	1,1
SM3	31	782	926	3,6	7,1	251	14,0	1,0
SF0	28	722	1423	2,7	9,0	204	17,4	3,5
SF1	33	798	1209	2,8	5,4	225	17,6	2,2
SG0	34	938	1043	3,1	5,6	221	13,2	0,5
SG1	30	689	810	3,1	4,4	190	15,6	1,0

(1) After 181 days of drying

(2) The spherical (entrained) air voids were counted separately from the compaction voids (which have an irregular shape)

The values of the volume of permeable voids for the ten mixtures made with the type 10 cement and silica fume, which vary between 13,2% and 19,7% with an average of 16,5%, do not indicate any significant influence of the fine and coarse aggregate, nor of the use of polypropylene fibers. The scatter of the data is relatively large, and could be due in part to the high air contents in these shotcretes, since some of the air voids can become filled with water during the test (which of course influences the calculated value of the volume of permeable voids). The average value for the three mixtures made with the type 30 cement, at 16,7%, is approximately similar, and thus indicates no significant influence of the type of binder on the results of this test.

The compressive strength of all mixtures varies between 28 to 39 MPa. These values are low, particularly considering that most mixtures contained silica fume. However, the volume of permeable voids, even if it is quite variable, is normal for this type of shotcrete. These low strength values, which do not appear to vary with any of the parameters tested (use of fibers, aggregate grading, and type of binder) are probably therefore more related to the air void system (particularly the volume of the compaction air voids which is always relatively high) than to the quality of the paste.

The results in Table 4 indicate no significant influence of any of the parameters tested (use of fibers, aggregate grading, and type of binder) on the value of drying shrinkage. This was to be expected, since the amount of binder was approximately constant for all mixtures (see Table 2), and the influence of silica fume on drying shrinkage is generally small [7]. The scatter of the data is relatively large, and is probably due to variations in the amount of water added to the mixtures. Such variations are normal for this type of shotcrete.

The chloride ion permeability of the ten mixtures containing silica fume is much lower than that of the other three mixtures. This is certainly related in good part to the reduced amount of alkalies in the pore water solution of cement pastes containing silica fume [8], since this increases the resistivity. Globally, the results of this test indicates no significant influence of the fibers. However, the permeability tends to decrease with an increase in the proportion of coarse aggregate. The scatter of the results for this test can also be related in part to normal variations of the water to binder ratio of this type of shotcrete, but the very large variations in the group of three mixtures made with the type 30 cement remain unexplained.

The mixtures for this project were all made with an air-entraining admixture. Since the average air void spacing factor for all mixtures is 218 μm, and all values are lower than the 260 μm limit specified in the Canadian code, these tests thus confirm that air-entraining admixtures can be used in dry-mix shotcretes to obtain a satisfactory air void system. It can be seen in Table 4 that, in all mixtures, the volume of the spherical air voids is quite significant (it ranges between 2,7% to 3,6%).

The amount of scaling residues for the three mixtures made with the type 30 cement is small in all cases, and indicates no significant influence of the fibers. The amount for the ten mixtures containing silica fume is generally much higher, and indicates that the resistance to scaling tends to increase with the proportion of coarse aggregate, and also perhaps with the fineness modulus of the fine aggregate. The lower scaling resistance for the silica fume mixtures, even if the air void spacing factors were adequate, could be related to the poor dispersion of the silica fume particles, as observed in a previous series of tests [5]. The higher amount of scaling residues for the fiber-reinforced mixtures containing silica fume (compared to that of the reference mixture), could be related to the higher air void spacing factor.

Conclusion

The tests described in this paper indicate that the use of polypropylene fibers in dry-mix shotcretes made with type 30 cement or type 10 cement with silica fume did not significantly modify any of the properties that were evaluated, i.e. compressive strength, toughness, drying shrinkage, chloride ion permeability, and deicer salt scaling resistance. Polypropylene fibers are normally used to control early age cracking, and the results obtained indicate that it is possible to add up to 4 kg/m^3 of these fibers (in the dry materials) without any negative effect on the properties of the hardened concrete. Although certain variations in the test results were observed, most of them can probably be attributed to variations due to the shooting process, mainly as regards the amount of water added to the mixture and the volume of the compaction air voids.

The results of the tests further show that the grading of the aggregates (i.e. the fineness of the sand and the proportion of the coarse aggregate) did not have a very large influence on any of the properties that were measured, although the use of a coarser sand and an increase in the proportion of the coarse aggregate was found to improve slightly the deicer salt scaling resistance. This phenomenon is difficult to explain, and more research would be needed, firstly to confirm it, and secondly to determine the mechanisms involved.

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