SNO-STR-90-52

LOW-ACTIVITY CONCRETE PREPARATION AND TESTING AN UPDATE

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April 15, 1990

INTRODUCTION

The mark II design for the Sudbury Neutrino Observatory Detector features a barrel- shaped cavity (maximum diameter 22 m) and a spherical acrylic heavy water tank. Shielding calculations have shown that the original requirements for extra-low Sulfurcrete shielding (1 m thick) around the entire H_2O tank, at the cavity wall, can be reduced due to the shielding provided by the additional water layer present in the larger cavity (1). The Mark II design currently specifies a layer of low-activity concrete (with Haley Dolomite aggregate and a boron additive) around the waist of the cavity only, with normal concrete filler between the water tank and the cavity rock face at all other locations. In the investigations described below, low-activity concrete specimens were prepared and evaluated for possible use in the detector shielding.

Concrete preparations with neutron shielding admixtures are used in conjunction with nuclear reactors or fusion experiments. Some methods of preparing a concrete with a boron additive have included the production of a boron containing fit, the addition of an aggregate containing some naturally occurring boron, the use of paints containing boron or a polymer impregnated with a boron compound. The boron frit is produced by the fusion of boric acid (H_3BO_3), limestone ($CaCO_3$), silicon oxide (SiO_2) and aluminum oxide (Al_2O_3) at temperatures of about 1200°C or the sintering of minerals such as colmanite, baryte and limestone (2). The paints and polymers are commercially available, but prohibitively expensive for large scale usage.

MATERIALS SELECTION

The goal of this concrete prototype work was the preparation of normal concrete samples, using selected low-radioactivity portland cement, Haley dolomite aggregate, and a boron additive to enhance the absorption of thermal neutrons. In order to meet the design parameters used in recent shielding calculations, the concrete should have uranium levels of near 300 ng/g, thorium levels near 200 ng/g and an equivalent boron content of 0.25 % to 1.0 %.

A survey of Canadian Canada Lafarge cement plants was carried out in 1985 (3). Tests of samples of Portland cement from each plant, for thorium and uranium content, were carried out using neutron activation analysis. Using these results, Portland cement samples were obtained from the two Lafarge plants whose cements previously showed the lowest uranium and thorium content (plant # 9, 900 ng/g uranium (^{238}U), 3,300 ng/g thorium, plant # 14, 1,700 ng/g uranium, 700 ng/g thorium). Crushed dolomite from Timminco Ltd. Haley, Ontario was obtained for use as an aggregate. Borax (sodium tetraborate decahydrate - reagent grade), boric acid (crystal and powder - reagent grade), sodium tetraborate (anhydrous, fused-ground and in chip form) were used as sources of boron.

EXPERIMENTAL

The approach taken in this work is the incorporation of a boron compound into the chemical structure of the concrete. The constraints are taken to be: 1) the concrete must have structural integrity 2) the mix design should be easily adapted to standard concrete construction techniques 3) the process should be as inexpensive as possible. The introduction of boron containing compounds to a concrete mix often causes a reduction in the rate of hydration (4,5). Attempts to offset the set retardant effects with compounds known to accelerate the set such as calcium chloride, potassium and sodium hydroxide, gypsum and others proved to be ineffective. The best results to date have been obtained by reacting boric acid and calcium hydroxide in a surplus of water by heating the reactants to boiling then kiln drying at about 300°C to drive off residual water. A second promising approach involved the addition of calcium hydroxide or calcium oxide and sodium tetraborate (decahydrate, fused-ground or chips) directly to the concrete while mixing. In the first case the set time was about 10 - 12 hours while in the second case the concrete takes up to 3 days to set. The much higher uniaxial compressive strengths of these samples set them apart from other mix designs.

TABLE 1 - SUMMARY OF CONCRETE BATCHES PREPARED
ALL INGREDIENTS GIVEN IN WEIGHT %

BATCH and SAMPLE	CEMENT	WATER	AGGREGATE	ADDITIVE	FORM	W/C RATIO	BORON %
P1	18	9	73	Standard Concrete Mix Design			
P2	18	9	68.6	4.4	a	0.5	0.05
P3.1	20	9	69.5	1.5	b	0.45	0.25
to P3.5	31	10	57.3	1.5	b	0.32	0.25
P3.6	31	10	56.6	2.2	a	0.32	0.25
A7	20	9	64	7.0	b,d	0.45	0.50
A8	20	10	46.7	23.3	c	0.5	5.00
A9	20	10	65.4	4.6	c	0.5	1.00
A10	24.4	12.1	57.7	5.94	c,d,f	0.49	1.04
A11	19.4	12.6	59.2	8.8	e,g	0.65	1.04
A12	18.2	17.2	54.4	10.2	c,g	0.95	1.23
A13	20	10	60	10	a,g	0.5	1.00
A14	23.4	21.3	49.7	6.6	b,d	0.9	0.70
A15	21.7	17.4	49.5	11.4	b,g	0.8	0.94

ADDITIVES

a Sodium Tetraborate Decahydrate $Na_2B_4O_7 \cdot 10H_2O$

b Boric Acid H_3BO_3

c Sodium Tetraborate fused $Na_2B_4O_7$

d Calcium Hydroxide $Ca(OH)_2$

e Sodium Tetraborate chips $Na_2B_4O_7$

f potassium Hydroxide 0.1 M solution KOH

g Calcium Oxide CaO

PREPARATION

Batches .of about 10 - 20 kg. concrete were prepared in a standard concrete mixer using standard construction methods (4). The weight % mix proportions are listed in Table 1. In some cases the boron additive was pretreated while in other cases it was simply added to the concrete during the mixing process. Standard test cylinders 3" in diameter and 6" in height were prepared by filling the molds 1/3 a time and rodding each layer 25 to 30 times into the previous third. Molds for radiation measurements using Marinelli geometry, a cylinder 3" high 1" thick and 6" in diameter with a 1" thick 6" diameter disc-cap, were prepared for some of the batches. Samples were allowed to set for 3, 7, 21 or 28 days depending on the requirements of the strength testing schedule.

COMPRESSIVE STRENGTH TESTING

The uniaxial compressive test results were obtained from a Tinius Olsen press made available by the Civil Engineering Department at Laurentian University. The calibration is performed by the independent consulting firm "Calibration Canada" and is considered to be of high enough accuracy for the purposes of these

TABLE 2 UNIAXIAL COMPRESSIVE STRENGTHS

Batch	No. Samples	Curing Time	Uniaxial Compressive Strength (MPa)
P1	Normal concrete mix	28	28 ± 2
A7	5	3	11.14 ± 3.18
A7	9	21	17.45 ± 2.73
A8	2	7	6.5
A8	3	28	8.6 ± 0.87
A9	6	28	12.14 ± 1.7
A10	6	28	14.36 ± 4.1
A11	6	28	8.2 ± 0.63
A12	6	28	16.26 ± 1.1
A14	6	28	15.9 ± 0.9
A15	5	28	18.2 ± 0.9

tests. The test samples are capped with a compound such that the contact ends are parallel; this ensures that the force is evenly distributed over the entire cross sectional area of the sample. The methods used agree with CSA/ASTM regulations. Other than the P1 mix (normal concrete) all batches prepared up to A7 were found to be very weak, either crumbling during extraction from the molds or showing very low, less than 2 MPa, uniaxial compressive strengths. The average strength of the more successful batches are listed above.

CONCLUSIONS

This study has demonstrated that low activity concretes, containing boron additives, can be prepared, using the standard approved construction techniques, from readily available materials Levels of 500 ng/g appear to be achievable, and boron loading up to 1% by weight with high strength or 5 % at lesser strengths are feasible. Further long term strength tests are currently underway.

OTHER CONCERNS

SHOTCRETE:

A considerable amount of shotcrete is required for ground support purposes. The surface of the shotcrete will have to be able to be cleaned easily and not contribute dust to the laboratory environment. The surface of shotcrete placed by the standard methods tends to be quite irregular. In order to create a smooth surface a second layer of shotcrete, prepared from fine sand and having a slightly higher water content than the standard shotcrete, can be placed and troweled. Another approach may be the use of a latex-concrete parging coat. The parging coat can be placed and smoothed by hand.

COATINGS:

The concrete surface can be coated to suppress dust entrainment and ease the cleaning. Some water emulsion acrylic coatings have been tested on the surface of a styrocrete, standard concrete and latex-concrete, in all cases the surface has proven to be easily cleaned with water. Some shotcrete panels have been prepared at Mcreedy mine west and are expected to be available for further testing in the near future.

REFERENCES

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