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EXPLANATION:
1. Specimen Size - 5"x 6"x 10"
2. Moist Curing Period, 14 days.
3. Each Point - Average of 3 specimens.
4. 1½ inch MSA.
5. Note Table 1 for Mix Data.
EXPLANATION:
1. Tests as per ASTM.
2. 1½ Inch MSA
3. Lignin Admixture
4. Cem. Content 5,5 SKS/C.Y.
5. Note Table 1 for Mix Data
EXPLANATION:
TESTS AS PER A.S.T.M.
1. 1/2 Inch MSA
2. Lignin Admixture
3. Cem.Cont. 5.5-5.75 SK./C.Y.
4. Note Table 1 for Mix Data

PENETRATION RESISTANCE - P.S.I.

TIME - HOURS AFTER MIXING

VIBRATION LIMIT

CONTROL W/WR. ADMIX.

WASHED

UNWASHED +
No. 30 SIEVE

UNWASHED
EXPLANATION:
1. 1/4" inch NSA
2. Lignin Admixture used in the construction of the Positron Radiator structure. CEM.
3. 5,75 SKS/C.Y.
4. CEM. CONT. TESTS. 5.5, SKS/C.Y.
5. AGE - DAYS

COMPRESSIVE STRENGTH - P.S.I.

7000
6000
5000
4000
3000
2000
1000
0

STANFORD LINEAR ACCELERATOR—M
U.S. ATOMIC ENERGY COMMISSION

AETRON - BLUME - ATKINSON

ENGR. E.W.O. CHK'D
DFTS. APVD

DATE 7/21/64 DWG. NO.
SCALE

FIGURE 2

REV

PRINTED ON DIELPO NO. 1000H CLEARPRINT
EXPLANATION:
1. 1\(\frac{1}{2}\) Inch MSA
2. 6" x 12" STD. Cure Specimens
3. Lignin Admixture
4. Research Complex Concrete
5. Cem.Cont. 5.5-5.75 SKS/C.Y.
6. Refer to Table 1 for Mix Data
EXPLANATION:
1. Specimen Size - 5" x 6" x 16"
2. Moist Curing Period, 14 days.
3. Each Point - Average of 3 specimens.
4. 1\frac{1}{2} inch MSA.
5. Note Table 1 for Mix Data.

DAYS DRYING @ 50% RELATIVE HUMIDITY AND 70°F.
EXPLANATION:
1. Specimen Size: 5" x 6" x 16"
2. Moist Curing Period: 14 days
3. All Mixes with WR-Admixture
4. Each Point Average 3 Specimens
5. 1/2 Inch Max. Size Aggregate
6. Refer to Table 1 for Mix Data

DAYS DRYING @ 50% RELATIVE HUMIDITY AND 70°F

PERCENT - SHRINKAGE

SPEC. MAX.

CONTROL

PLUS #30

WASHED

UNWASHED

21 DAY

0.050
0.040
0.030
0.020
0.010
0.000

0
14
21
28
42
56
90

FIGURE 6
EXPLANATION:
1. Specimen Size - 5"x6"x16"
2. Moist Curing Period - 14 days
3. Each Point - Average of 3 Specimens
4. 1-1/8 inch MSA
5. Note Table 1 for Mix Data

DAYS DRYING @ 50% RELATIVE HUMIDITY & 70°F.
EXPLANATION:
1. Tests as per A.S.T.M.
2. 1½ Inch MSA
3. Lignin Admixture
4. Cem. Cont. 5.5 SKS/C.Y.
5. Note Table 1 for Mix Data

CONTROL, NO WR. ADMIX.
CONTROL W/WR. ADMIX.
FRIT, NO. WR. ADMIX.
FRIT W/WR. ADMIX.

VIBRATION LIMIT

TIME - HOURS AFTER MIXING
**EXPLANATION:**

1. Tests as per ASTM.
2. 1½ Inch MSA
3. Lignin Admixture
4. Cem. Content 5.5 SKS/C.Y.
5. Note Table 1 for Mix Data
EXPLANATION:
TESTS AS PER A.S.T.M.
1. 1\frac{1}{2} Inch MSA
2. Lignin Admixture
3. Cem.Cont. 5.5-5.75 SK./C.Y.
4. Note Table 1 for Mix Data

VIBRATION LIMIT

TIME - HOURS AFTER MIXING

WASHED
UNWASHED +
No.30 SIEVE
UNWASHED
1. 1\(\frac{1}{2}\) Inch Max Size Agg.
2. Concrete Temp. 58°F.
3. Air Temp. 50°F to 55°F.

1. All Mixes with WR. Admix.
2. 1\(\frac{1}{2}\)" Max, Size Agg.
3. Concrete Temp. 60°F.
4. Air Temp. 60°F - 65°F.
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<th>&quot;FLEMING&quot; WETTRE COMP</th>
<th>&quot;COLEMANITE&quot;, KERN COUNTY LANE COMP</th>
<th>&quot;COLEMANITE&quot;, LANE COUNTY LANE COMP</th>
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<td>No WR Admix</td>
<td>W/WR Admix</td>
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<tr>
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<td>24 hr-15 min</td>
<td>5 hr-0 min</td>
<td>17 hr-0 min</td>
<td>5 hr-45 min</td>
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<td>Vibration Limit (500 psi)</td>
<td>8 hr-15 min</td>
<td>30 hours</td>
<td>7 hr-15 min</td>
<td>22 hr-40 min</td>
<td>8 hr-15 min</td>
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Preliminary report on investigations of the effect of boron admixtures on concrete properties

Report to Stanford Linear Accelerator Center - ABA No. 97
Stanford University Subcontract S-136
Under ACC Contract AT(04-3)-400

Submitted by: E. W. Osgood

Approved by: H. B. Kilker

Actoro Blumei Atkinson
A Joint Venture
Architect - Engineer - Manager
Palo Alto, California

July 1964
Summary - Batch and Hot Water Properties of Cement

Table 1: Gradation of Various Boron Admixtures

Figure 1: Compressive Strength with Frit

2. Compressive Strength with Frit

3. Compressive Strength with Colemanite from U.S. Borax

4. Compressive Strength with Colemanite from Keen County

5. Drying Shrinkage - U.S. Borax Colemanite

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[2 pages, additional sheet]
Two test series were conducted to determine the effects of various types of "Boron" additives on the properties of normal job concrete. The first investigations were made prior to construction of the Positron Radiator portion of the Linear Accelerator Housing using boron frit and also a finely graded colemanite from U. S. Borax Company. The second series, as a part of the preliminary investigations for the Beam Switchyard, explored the use of colemanites from the mines of the Kern County Land Company. Following the completion of the first test series, additional routine tests were conducted on concretes with frits used in the construction of the Positron Radiator. Results of both test series and the tests of the Positron Radiator concrete are summarized and comparisons made.

Colemanite samples from the second source were also washed thoroughly to remove the excessive fines. In addition, unwashed raw ore as delivered was "upgraded" to a size range not finer than the No. 30 sieve size or larger than 3/8 inch. These beneficiated colemanites were also tested. The results of these beneficiations are described.

Several thousand cubic yards of shielding concrete with "Elemental Boron" will be required to complete the construction of facilities in the Target Area of the Stanford Linear Accelerator. In addition, Boron may be needed in the "Heavy Concrete" for the shielding blocks in the same area.

Test results indicate that quality concretes comparable to the concretes used in normal pressure construction can be obtained with boron frit or washed colemanite admixtures.
Approximately 300 cubic yards of "Boron Loaded" concrete, not covered in the Housing Contract, were needed in the Positron Radiator construction. Time demanded hurried preliminary concrete studies. These indicated that the use of "Frit" as a Boron additive presented few problems and/or detrimental effects on the various concrete properties. Tests made with colmanite, another boron source, were less favorable in this respect. The decision was made to use Frit as a means for boron loading. No placing problems were encountered nor were harmful effects noted.

Cost studies during these initial investigations showed that use of Frit was from 200 to 300 percent higher than with the colmanite ores. Therefore, in view of the remaining volume of shielding concrete required, it appeared necessary to conduct additional studies regarding the use of colmanite as a practical source of elemental boron.

Additional concrete tests were made with colmanite from a second source. Materials from this source were washed to remove excessive fines. Samples were also dry screened to produce a coarser gradation. Results with these beneficiated materials were compared with the basic ore as delivered and also with mixes without the additives.

Test results and observations during the testing of both types of additives and later results with the frit used during construction are summarized in this report.

**SUMMARY**

**MATERIALS**

The selected concrete materials used in the Accelerator Housing and Research Complex and for the Preliminary Investigations were all from the same sources.
With the possible exception of the water reducing admixture, they are expected
to be similar to those which will be used for the Beam Switchyard construction.

Cement - Type II, Modified - Specifications limited the tri-calcium silicate to a minimum of 42% and a maximum of 50% and not more than 6%
tri-calcium aluminate. The compressive strength (2" x 2" cubes), not less than 4500 psi at 28 days of age. Note Table 2 for the properties of cement used in the testing and Positron Radiator construction.

Fine aggregate - Monterey Bay - Santa Cruz area. These sands are reasonably well graded "feldspathic" sands composed predominately of quartz and feldspar. The particle shape ranges from subangular to angular. The sand used in the concretes with Colemanite No. 1 and the tests and job concrete with the boron frit had a fineness modulus of 2.65. The sand used in the tests with Colemanite No. 2 had a fineness modulus of 2.45. All within ASTM gradation limits.

Coarse Aggregate - "Granite" aggregate from the Watsonville area. This aggregate is quarried material from the "Santa Lucia" granite formation and is composed chiefly of quartz and feldspar with minor amounts of hornblende and biotite mica. The rock is sound, strong and only slightly weathered. Particle shape ranges from subangular to angular after processing. Aggregates used in two size ranges, #4 to 3/4 inch and 3/4 inch to 1-1/2 inch. Gradation was within ASTM limits with no more than 3% significant undersize.

Water Reducing Admixture - The admixture used was Water Reducing Admixture (Lignosulfonic acid) delivered in solution. Normal dosage 6 ounces/sack of cement.
Resin type agent Normal dosage 1/2 to 3/4 ounce per sack of cement in the concretes with the water reducing admixture and up to 1-1/4 ounces/sack in the plain mixes.

Colemanite - Colemanite is a naturally occurring mineral used principally as a source of boron. It occurs in crystalline masses interbedded with clay shales, sandstones and other sedimentary rocks in California and Nevada. Colemanite as extracted from the ground usually contains impurities such as sodium, clays, sands and silts, and small amounts of gypsum. These impurities, in excessive amounts, may produce significant and adverse effects on the properties of concrete.

"Colemanite" Number 1 was from the U. S. Borax and Chemical Company, Los Angeles. "Colemanite" Number 2 was from the Kern County Land Company's mines in Death Valley, California. The samples from U. S. Borax were very fine with approximately 50 percent minus the #50 sieve and 15 percent minus the #200 sieve. The material from Kern County was much coarser with 20 percent minus the #50 sieve and 5 percent minus the #200 sieve. Comparative gradations are shown on Figure 1. Significant amounts of clayey materials were present in both samples. These clays exist throughout each size fraction and are not isolated in the minus #200 size range. A part of the fines are bentonitic clays. Tests were conducted to establish the amounts of clayey materials. Approximately 600 pounds of the sample of the colemanite from Kern County was washed prior to use in the concrete. The material was pre-soaked for 24 hours followed by simple washing, comparable to conventional methods used to remove excessive fines from concrete sands. This pre-soaking appears advisable as nearly 35 percent fines were removed as a result of the washing. It should be noted, however, that the amount of fines in the various
raw samples varied from 20 to 40 percent which will significantly effect
total quantities, the amount of washing, and possibly the need for pre-
soaking. This may or may not be true in colemanites from other sources or
from selective mining from the above source. The B$_2$O$_3$ content of the
colemanites checked ranged from 18 percent unwashed to 25 percent washed.
Depending upon the amounts of the impurities, the total dosage of colemanite
per cubic yard of treated concrete could vary from approximately 200 to 300
pounds.

Several definite advantages were noted as a result of the washing. These are:

1) A significant reduction in the adverse effects noted with the unwashed
colemanite on the properties of the fresh and hardened concrete.

2) Increased B$_2$O$_3$ content for equal dosage. Total B$_2$O$_3$ content expressed
as a percent of the total sample increased from 18 to 25 percent as a
result of the washing.

3) Uniform addition of elemental boron per cubic yard of concrete at
minimum dosage.

4) Stabilized unit water requirement.

5) Removal of sodium and other water soluble salts.

Frit - Boron frit is a refined product produced by fusing boric acid, calcium
carbonate, silica and alumina and quenching the melted product in water.
When used as a boron additive in concretes, must be free of com-
pounds of sodium and potassium.
The $\text{B}_2\text{O}_3$ content of the high grade frit used is approximately 52 percent. At this $\text{B}_2\text{O}_3$ content, 100 pounds of frit is required to add 16 pounds of elemental boron to each yard of concrete.

The frit used in the preliminary testing and the Positron Radiator construction was fairly coarse with an average of 97 percent plus the No. 30 sieve size and 100 percent minus the 3/8" size screen. Note Figure 1. No problems were encountered in the handling, storage, batching or introduction of the material into the concrete mix during construction. Placability, workability and finishing time, etc., were comparable to the normal concrete used in construction of the Housing.

**CONCRETE MIX**

The concrete mixes were designed in accordance with the "Recommended Practice for Selecting Proportions for Concrete" (ACI 613-54). The amount of boron additive per cubic yard replaced an equal weight of sand.

**METHODS AND PROCEDURES**

The trial mixes were batched at the concrete batch plants furnishing concrete for the Accelerator Housing and the Research Complex. The minimum batch size was one-half cubic yard. The batches were mixed in transit mixers for a total of 80 revolutions after addition of all materials. Tests of the fresh concrete and the casting of the specimens for compressive strength, shrinkage, etc., were conducted at AETRON-ELUME-ATKINSON's field laboratory or the batch plant immediately following the mixing period. The test specimens were stored in the field laboratory or batch plant for 24 hours following casting, then transported to the testing laboratory or the laboratory of the University of California for curing and testing.
All tests were performed in accordance with applicable ASTM and/or ACI practices or procedures. Specimens for compressive strength were standard cured 6" by 12" cylinders. The specimens for the shrinkage determinations were 5" by 6" by 16" prisms. Moist curing period for the shrinkage tests was 14 days. Drying at 50 percent relative humidity and at 70°F Fahrenheit. Tests of the rate of hardening were made on mortars wet screened from the trial batches.

**TEST DISCUSSION OF RESULTS**

**COMPRESSIVE STRENGTH**

**With Boron Frit**

The preliminary tests indicated a strength loss with frit in the mixes with the water reducing admixture of approximately 12 percent. Comparison with and without frit of the concrete without the water reducing admixture showed a gain of nearly 10 percent. Later, during construction of the Positron Radiator, results of routine strength tests showed strengths through 28 days of age closely comparable to the original control mix without frit at a cement content one quarter of a sack higher. These comparisons are shown on Figure 2. The results also compare favorably with the results obtained with normal job concrete with the same materials and cement content.

**With Colemanite 41 (U. S. Borax)**

In Table 1 and Figure 3 are given the strength results with this additive. A strength gain at 28 days of age and longer was noted in the mixes with the colemanite, with or without the water reducing admixture. A greater increase was noted in the concretes without the admixture. The major portion of this indicated gain can be attributed to the complete loss of entrained air in the mix. It is doubtful if any strength advantage or disadvantage results from the use of the colemanite at equal water-cement ratios. Strengths at early
ages (3 days) of the mixes with the water reducing admixture are approximately 50% lower than control. This slow strength development is due principally to the excessive retardation. Figure 9, and will significantly affect the concrete finishing and early form removal, particularly at lower air temperatures.

With Colemanite #2 (Kern County)

Normal concretes with the water reducing admixture were compared with similar concretes with unwashed and washed samples from this source. Also, with unwashed material "up-graded" to a size range not finer than the number 30 sieve size and none larger than 3/8 inch.

Compressive strengths of the concrete with the unwashed material (regardless of the grading) averaged 4000 psi at 28 days of age as shown in Figure 4. This is from 28 to 32 percent below the strengths of the control mix. The high water demand (30% plus) for these mixes to obtain equivalent consistency and workability is considered the influencing factor controlling the lower strength and not the addition of the colemante.

Again, as was noted with the first colemante investigated, the compressive strengths at early ages (2 days) are proportionately lower than the plain mixes, Figure 4. However, the early strengths show significant improvement over the results with the first sample of colemante. This slower strength gain is due principally to the moderate retardation, Figure 10, and is not expected to impose any major problem during construction if the cement content is sufficient to produce overall strengths equal to the control mixes.

Strengths with the washed colemante were closely comparable to the control mixes except at two days of age as illustrated in Figure 4. A slowing of
the rate of hardening was noted with the washed colemamite which in all probability can be held accountable for the slower strength gain at early ages.

Strengths of the control mixes compare favorably with job concretes at W/C ratios equal to those used during construction. Compressive strengths of concretes with the frit and the washed colemamite (combined with the other materials comparable to those used in these tests) should easily meet the strength demands for the Beam Switchyard at cement content no higher than used in the mixes tested. Mixtures with unwashed colemamites similar to those tested would require considerably more cement due to the high water demand.

Drying Shrinkage

Favorable low drying shrinkage was noted in all of the tests. Shrinkage results after 21 days of drying were all below AETRON-BLUME-ATKINSON specification limitations of 0.0250%, and the results at later ages up to 90 days follow the general pattern and values of normal job concretes.

The shrinkage with colemamites from U.B. tested in the first series was extremely low. The total shrinkage at 90 days of age ranged from 26 percent to 42 percent lower than the control mixes with or without water reducing admixtures respectively, as shown in Figure 5. It is the writer's opinion that the water was "used up" by the fine, clayey materials in the boron additives resulting in lower drying shrinkage. This latter conclusion was supported by the second test series. The mixes with colemamites from the Kern County Land Company with approximately 30 percent higher unit water content (for equal consistency and workability) exhibited low shrinkage only slightly higher than the control mixes. Note Table 1 and Figure 6.

Boron frit, comparable to the frits tested, in combination with the materials used
in past construction has no significant influence on the drying shrinkage property. The comparisons are shown in Figure 7.

**VOLUME CHANGE** (Expansion)

During the second test series with Colemanite No. 2, measurements were taken of the drying shrinkage specimens during the moist curing period immediately following the casting of the specimens. No significant expansion was indicated by these tests.

**FLEXURAL STRENGTH** (Shrinkage Bar Specimens)

Tests in flexure, after completion of the drying shrinkage period (104 days of age), indicate that concretes with both types of boron additives can be expected to possess somewhat lower flexural strengths than normal job concretes. This lower factor is not considered significant in the type of construction connected with the Beam Switchyard. Test results are given in Table 1.

**SLUMP CHARACTERISTICS**

Slump losses are shown in Figure 11. None of the mixes with frit or Colemanites exhibited slump losses noticeably different than those of the control mixes. The control mixes also compare favorably with the job concretes. The low slumps with the first sample of Colemanite were due to low air and insufficient mixing water (note Table 1). There is no indication that any change in the rate of slump loss results from the use of Colemanite.

**AIR ENTRAINMENT**

Entrainment of air is difficult only in the mixes with the unwashed Colemanite. In the second test series the mixes with Colemanite required from 6 to 8 times
the dosage of A. E. agent in comparison with the control mixes and 4 times as much as the mix with the washed colemanite, note Table 1. Difficult control, possibly to the point of being dangerously poor, could result from use of these excessive amounts of agent. Poor control of the washing and/or batching could produce air contents from one extreme to the other causing wide variations in the consistency, workability, compressive strength, etc.

WORKABILITY

Good, plastic, workable mixes were obtained in concretes with both the boron frit and the "washed" colemanite. The mixes with the unwashed colemanites were highly plastic, extremely sticky, with nearly a complete loss of flowability at slumps from 3 to 4 inches. The stickiness appeared to be aggravated at higher air contents nearing 5%. Discharge from transit mixers, chuting, placing and finishing can be expected to be much more difficult, with these unwashed additives.

RATE OF HARDENING (Retardation)

The delay was more significantly and adversely affected by the addition of the boron additives.

Only moderate delays were noted in the mixes with the boron frit as shown in Figure 8. The initial retardation to the vibration limit or to point of maximum penetration were approximately 1½ hours longer than control. Limited delays such as this were not considered significant. Later, during construction of the Positron Radiator, the retardation noted during the testing was also apparent causing slight delays of approximately one hour in final finishing.

Severe retardation resulted from the use of colemanite from U. S. Borox. Figure 9 shows, the rate of hardening of the mixes without the admixture was
delayed nearly 16 hours longer than the control mixes and up to approximately 22 hours longer in mixes with the admixture. Corresponding delays in job concrete would result in costly delays in finishing and possibly in form removal. This retardation could possibly be extended much longer at the low concrete temperatures (below 50°F) proposed in the Beam Switchard. Winter temperatures which will be much lower than the seventy degree at which the tests were run, will also contribute to increased retardation.

Noticeably less retardation occurred in the mortars with colemanite from Kern County in comparison with similar mortars with Colemanite No. 1. The best results were obtained with the washed colemanite with the rate of hardening to maximum penetration delayed slightly over two hours longer than control. This delay increased to 3½ hours with the coarse material plus the #30 sieve and up to 5 hours longer with unwashed ore as delivered. Figure 10 compares these values. It was first thought that removal of the heavy clayey materials from the colemanite would eliminate the excessive retardation. This has not proven to be true. Time of set is improved with the washing; other minerals apparently influence this property and some abnormal retardation continues. 

Notice the retardation apparently must be expected with these boron additives. Mr. J. O. Henrie in his report (1) points out the problems of increased setting time with similar types of additives but from different sources. Author's own tests indicate that similar results must be expected with these materials, and unless some type of accelerator is used to overcome the extended retardation, the construction problems resulting from the delays must be accepted.

CONCLUSIONS

1) Quality concrete, consistent with the high standards adopted for the construction work on this project, can be obtained with the shielding concrete with frit or the washed colemanites tested.

2) Only washed colemanite or the boron frit should be considered as the required boron concrete for the Beam Switchyard.

3) Moderate retardation resulting from the use of the frit or washed colemanite should not impose any difficult or costly problems during construction.

4) Specifications controlling the concrete to be used should limit or control:

(a) Amounts of undesirable impurities;
(b) Gradation;
(c) Tests to establish amounts of boron or B₂O₃ in material as delivered to the job site;
(d) Maximum quantity of fines minus the #200 sieve permissible in the washed colemanite; and,
(e) Methods of handling, batching, batching controls.

5) The preceding text has described the beam admixture test program. Results of the tests conducted indicate the following conclusions and recommendations.
APPENDIX
### Properties of Cement

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**Table 2**

- Silo 14: Used in tests with Colemanite #1 and boron frit
- Silo 12: Used in tests with Colemanite #2 and positron radiator structure