# Report on
# Sulphate Resistance of
# KRYSTOL Treated Concrete

Prepared for

Kryton International Inc.

by

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## 1.) Introduction

R. M. Hardy & Associates were approached by Kryton International Inc. and asked to investigate the effect of their waterproofing product "Krystol" on the sulphate resistance of structural grades of concrete. More specifically we were requested to carry out a comparative assessment of "Krystol" with the waterproofing material "Vandex".

"Krystol" is essentially a special formulation of certain inorganic chemicals, Portland cement and a fine silica sand. It is mixed with water to a slurry consistency and applied to the surface of concrete products, by a brush or spray. "Krystol" is manufactured in two types:

Krystol T1: this is applied as a first coat and has a higher concentration of inorganic chemicals than:

Krystol T2: which is applied as a second coat to reinforce the first coat, and has a higher concentration of Portland cement.

The method of application of "Vandex" is similar to that described above for "Krystol".

"Krystol" is sold primarily for its waterproofing abilities. Tests conducted by R. M. Hardy & Associates Ltd. have shown that it acts as an in-depth waterproofer in concrete products. While it is applied as a surface coating, it reacts with moisture in the concrete to form a solution, which, by osmotic pressure and other physical forces is able to penetrate the capillary pores of the hydrated Portland cement system. As moisture is consumed in the cement hydration reactions, the "Krystol" chemicals are precipitated in the capillary pores in a crystalline form. This serves to reduce the porosity and hence improve the impermeability of the treated concrete.

Sulphate attack occurs by the penetration of solutions of different sulphate salts into the pore structure of hardened concrete. It is well-known that the less porous, and more impermeable the concrete, the less the potential for deterioration of the concrete due to sulphate attack. It could thus be postulated that "Krystol", with its ability to reduce the permeability of hardened concrete, could reduce the potential for sulphate attack. The purpose of this investigation was to examine the validity of this postulate.

## 2.) Sulphate Attack

In certain areas (particularly the western plains of Canada) a high concentration of sulphates in soil and groundwater has resulted in severe disintegration of concrete structures. Dry concrete, in dry sulphate bearing soils will not be attacked, but where concrete is subjected to continuous saturation in sulphate-bearing groundwater, attack may be rapid and severe. It is even more severe where saturation and drying are frequently alternated. The most common and aggresive sulphates are those of sodium and magnesium.

Two types of sulphate attack can occur. In the first, sulphate salts from outside the concrete can penetrate in solution and react with tricalcium aluminate hydrate in the hydrated cement to form calcium sulphoaluminate within the framework of the hydrated paste structure. The increase in volume of the solid phase is 227 per cent. A second type of reaction occurs between the sulphates and calcium hydroxide in the hydrated cement, resulting in the formation of gypsum (calcium sulphate) with an increase in the volume of the solid phase of 124 per cent. Since both of these reactions are expansive, gradual disruption and disintegration of the concrete results.

A variety of tests for sulphate attack have been devised over the years. Tests under normal exposure conditions may take many years to assess the relative merits of different concretes. Consequently most tests currently used by government authorities (such as the U.S. Bureau of Reclamation, and U.S. Army Corps of Engineers) rely on accelerated sulphate tests for evaluating the sulphate resistance of concrete. The effects are usually assessed by loss in strength, reduction in dynamic modulus of elasticity, expansion or weight change of concrete specimens.

In this investigation it was decided to adopt a modified form of a test developed by the U.S. Bureau of Reclamation, in which the reduction in strength, expansion and weight change of specimens subjected to alternate soaking in sodium sulphate solutions and oven drying were monitored.

## 3.) Experimental Program

Six 6" X 3" X3" concrete prisms were cast from a nominal 6000 $lb/in^2$ compressive strength concrete mix. In addition, four 4" DIA. X 8" concrete cylinders were cast for assessing the strength at 7 and 28 days under standard moist curing conditions. The prisms were cured in a fog room (at 95% R.H. and 72°F.) for 24 hours and then stripped from their moulds. Length change measuring targets were attached to two faces of the prisms using an epoxy resin. The specimens were returned to the fog room.

Three days after casting, two of the prisms were coated with "Krystol" and two with "Vandex" as per the manufacturer's instructions. After the final coating, the specimens were allowed to cure in the fog room for one week. Two untreated "Control" prisms were subjected to the same curing regime.

The specimens were removed from the fog room, oven dried at 130°F. for 24 hours, and allowed to cool in a dessicator over calcium chloride crystals for one hour, after which zero length and weight measurements were taken. Length was measured to an accuracy of 0.0001 inch over a 4 inch gauge length and weights recorded to an accuracy of 1 gram on a Mettler balance.

The specimens were then subjected to the following cycle of testing:

3:30 p.m.: Immerse all specimens in a 10% solution of $Na_2SO_4$.

7:30 a.m.: Remove from solution and place in an oven at 130°F.

2:00 p.m.: Remove from oven and place in dessicator over $CaCl_2$ crystals to cool.

3:00 p.m.: Weigh specimens and determine length.

3:30 p.m.: Return to $Na_2SO_4$ solution.

This cycle was repeated five times, (cycles 1 to 5). During weekends the specimens were left in the sulphate solution. The sulphate concentration was increased to a saturated solution for the remaining cycles (cycles 6 to 21).

The prisms were visually assessed for sulphate attack. After 12 cycles, when considerable surface and edge attack was apparent on all specimens, the loose material was removed by brushing with a steel brush, a new weight change datum established, and the soaking and drying cycles continued (cycles 13 to 21). Length change measurements were discontinued after 10 cycles, because of surface deterioration making further readings unreliable.

At the conclusion of cycle 21, six 2" square cubes were cut from the prisms. These cubes were examined under an optical microscope and then sulphur capped and tested to destruction in compression.

## 4.) Observations and Discussion

### a) Weight Change & Visual Assessment

Details of the weight change characteristics of the "Krystol" and "Vandex" treated concrete prisms, as well as the plain "Control" concrete prisms are tabulated in Table Al in the Appendix. The average values for weight change in two similar prisms for the first 12 cycles of test are shown in Figure 1. The average weight change values in prisms for cycles 13 to 21 are shown in Figure 2.

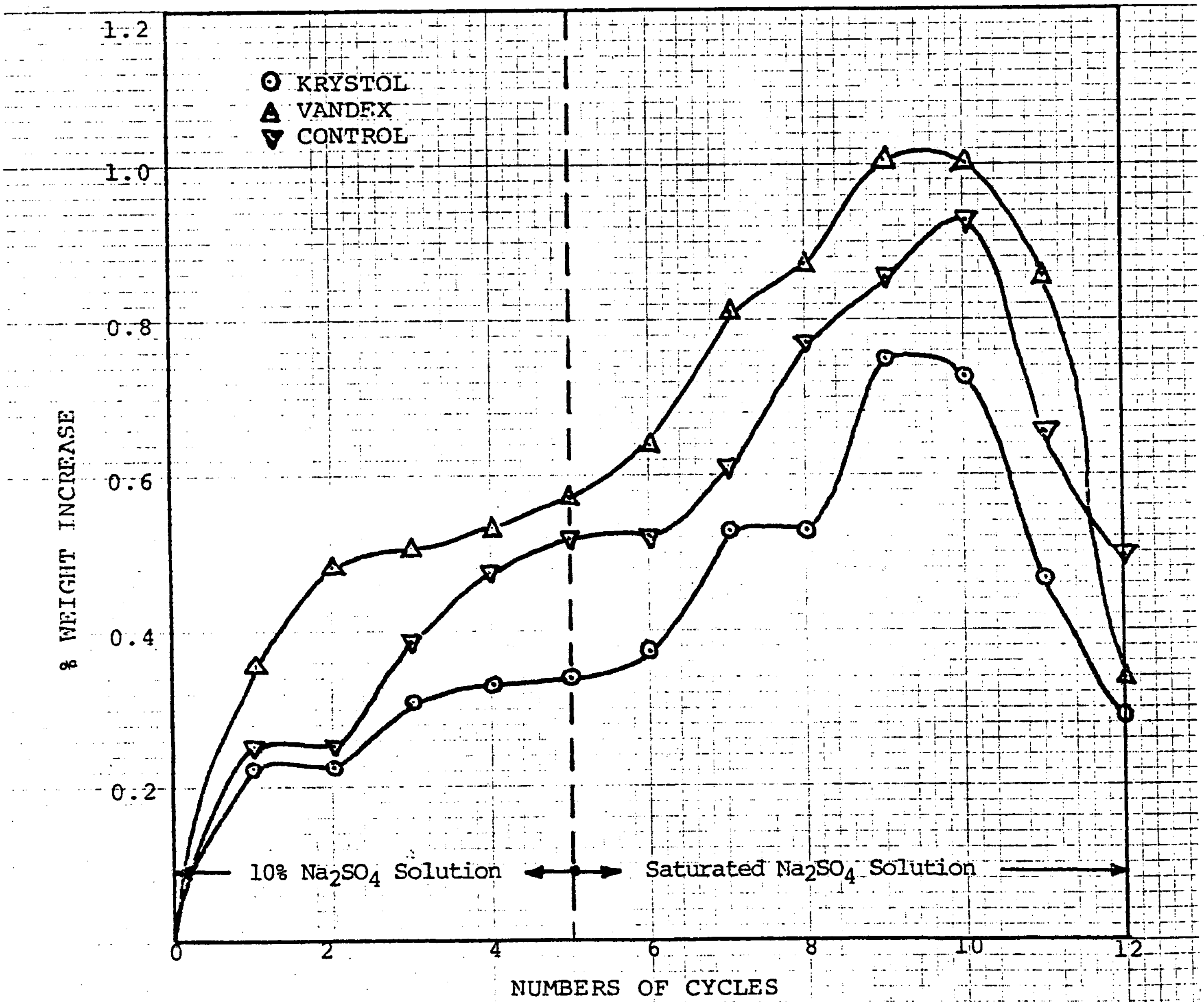


Figure 1 : PERCENT INCREASE IN WEIGHT OF CONCRETE PRISMS WITH REPEATED CYCLES OF TEST.

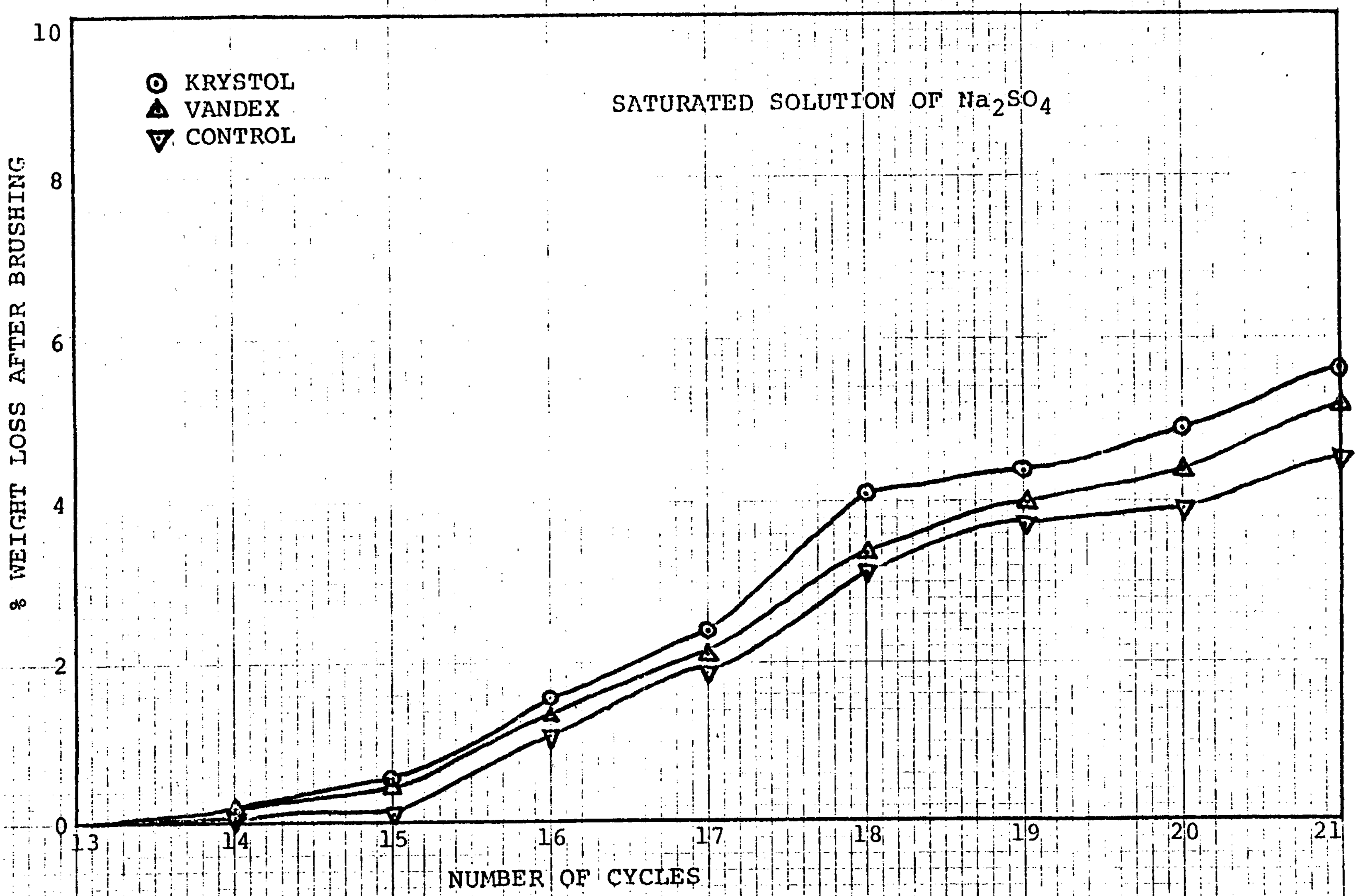


Figure 2 : PERCENT DECREASE IN WEIGHT OF BRUSHED CONCRETE PRISMS WITH REPEATED CYCLES OF TEST.

While there is a variation in weight change characteristics between similarly treated pairs of prisms, the general trends are well illustrated in Figure 1. On average the "Krystol" treated prisms show less increase in weight from cylces 1 to 10 than either the "Vandex" or "Control" concrete prisms. This observation supports the hypothesis that the in-depth reduction in permeability of the "Krystol" treated specimens is reducing its potential for sulphate attack. This effect would probably be even more pronounced had the tests been conducted on a more porous concrete. The concrete prisms made all had a water/cement ratio of 0.4. This fairly low water/cement ratio would normally ensure fairly good sulphate resistance in concrete because of the relatively low porosity of the hydrated cement paste. Nevertheless, the "Krystol" treatment was still able to effect improved resistance to sulphate attack in this concrete, as reflected in the reduced weight gain characteristics.

Visual examination after 5 cycles gave no evidence of any major deterioration in the prisms. Small cracks were evident in the surface coating of the "Krystol" and "Vandex" treated prisms, and surface dusting in the untreated "Control" prisms. Each cycle could be considered to correspond to about 1.5 to 3.0 years of natural aging in a sulphate environment. Hence, after about 8 to 15 years all the concretes could be expected to show no significant distress due to sulphate attack.

After 5 cycles the concentration of the sulphate solution was increased from 10% to a saturated solution and the prisms immediately started to show increased rates of weight gain from cycles 5 to 10. By cycle 10, surface deterioration and edge damage was apparent and the surface coatings of both "Krystol" and "Vandex" were starting to show disruption and spalling. After cycle 10 all specimens showed a decrease in weight, as disrupted concrete particles became detached from the prisms. Figures 3 and 4 illustrate the prisms after 12 cycles of test.

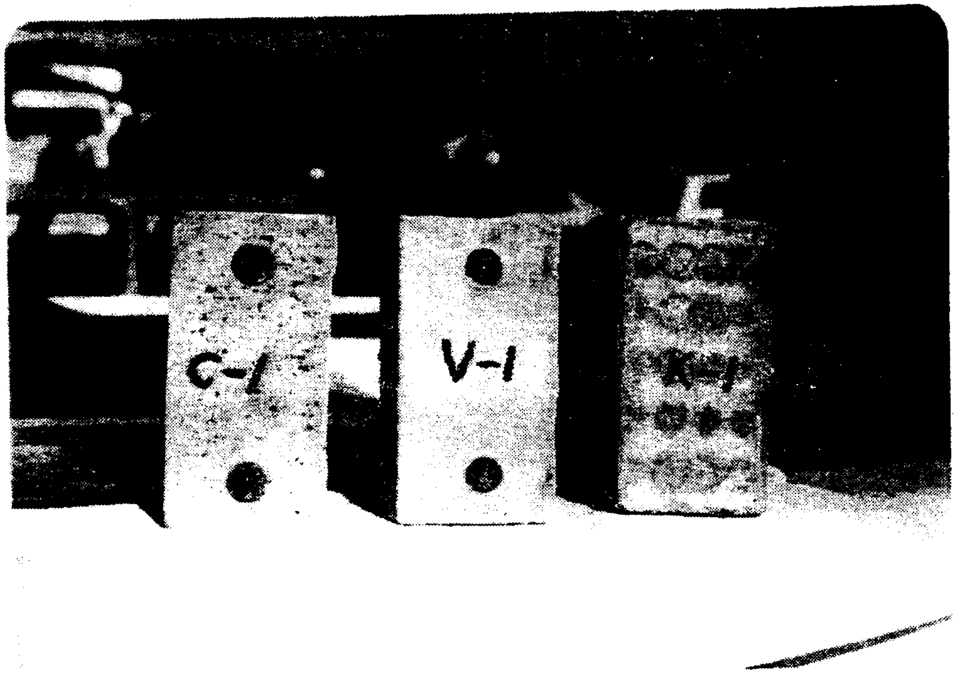


Figure 3 : Prisms after 10 cycles of test.

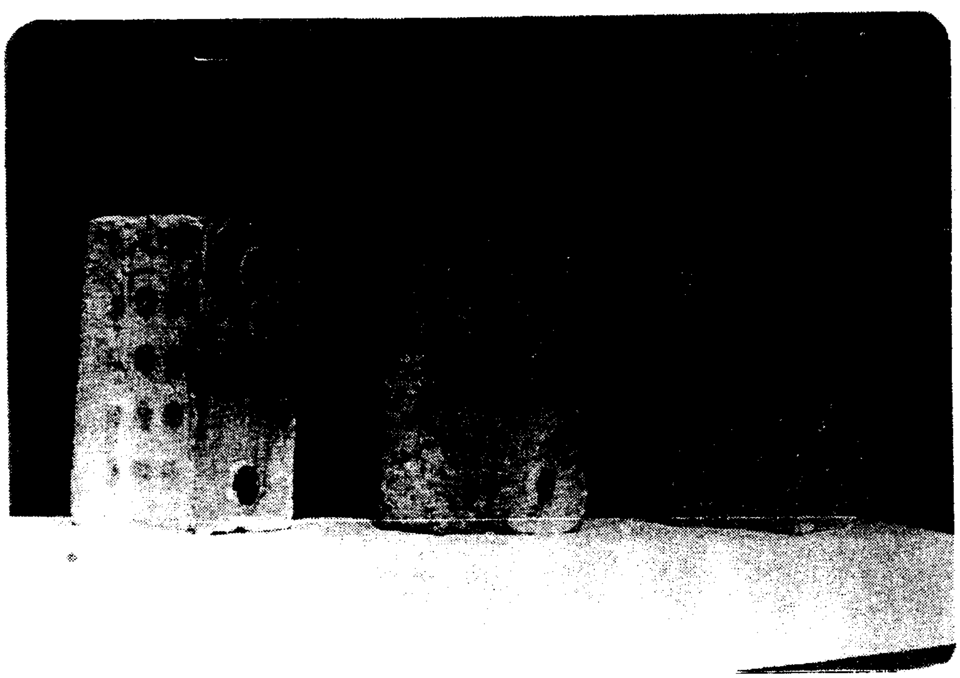

Figure 4 : Prisms after 10 cycles of test.

The surface attack, and exposed aggregate in the "Control" specimens (C-1 and C-2) is readily apparent, as is some corner damage. Considerable loss of surface coating, and some surface attack is apparent in the "Vandex" specimen V-2. Spalling of the surface coating in the "Krystol" specimen K-1 is also visible. Figure 5 shows the surface coating after it had been physically broken away from the prism.

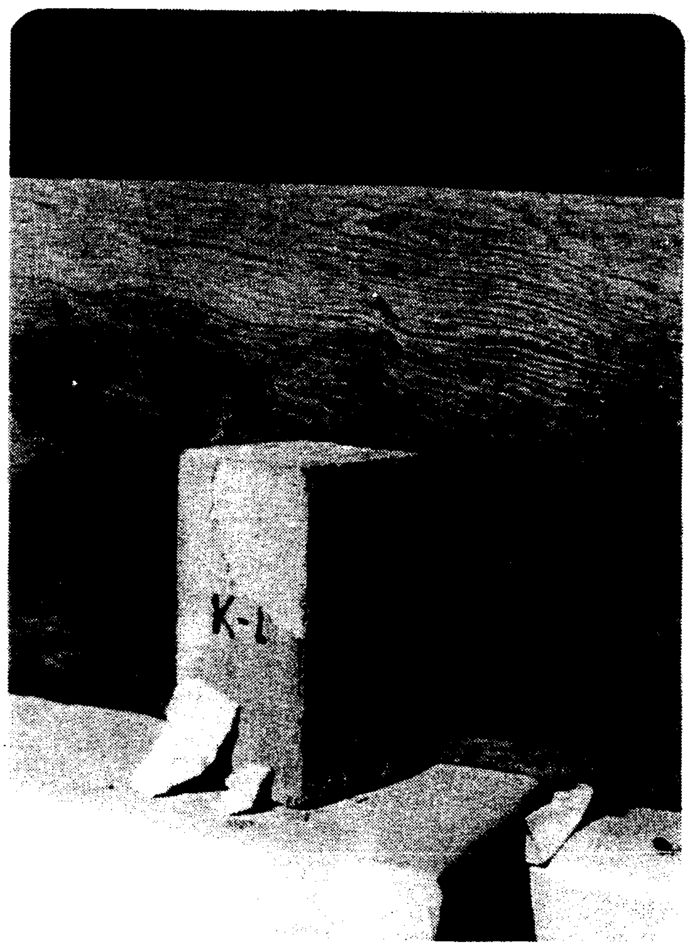


Figure 5 : "Krystol: treated prisms after 12 cycles.

In view of the increased concentration of the sulphate solution in cycles 5 to 10, it appears that all the concretes tested could be expected to show reasonable resistance to sulphate attack over a period of about 20 to 30 years, with the "Krystol" treated concrete outperforming both the "Vandex" treated and "Control" concretes. Sulphate attack would be mainly restricted to surface deterioration, and minor edge and corner spalling. The loss of the surface coating of "Krystol" and "Vandex" is in itself not serious, as the benefit of these materials lies in their in-depth penetration of concrete.

After cycle 12 the concrete prisms were all vigorously brushed with a stiff wire brush to remove any loose material. They were then subjected to continued cycles of testing (cycles 13 to 21). The results of weight changes are illustrated in Figure 2. Considerable weight loss ensued in all the prisms.

The plain "Control" concrete appears to be performing better than the treated concretes, but this effect is largely caused by the almost total loss of surface coating in the treated prisms. There was no apparent difference in the appearance of the different prisms after 21 cycles of testing. Photographs of the prisms after 21 cycles of testing are shown in Figures 6, 7, 8 and 9.

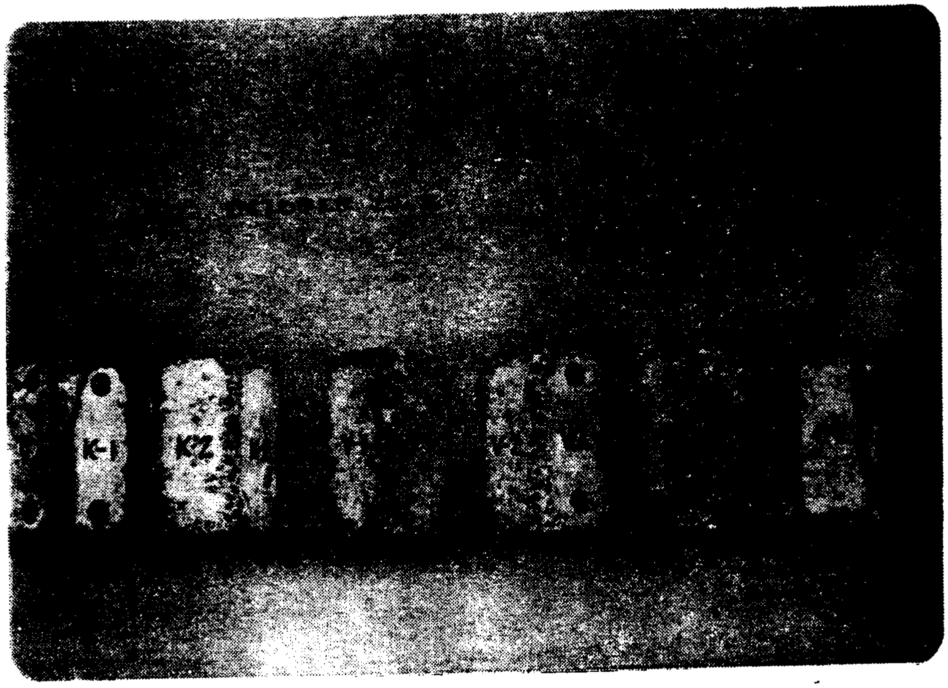


Figure 6 : General View of all specimens after 21 cycles of test.

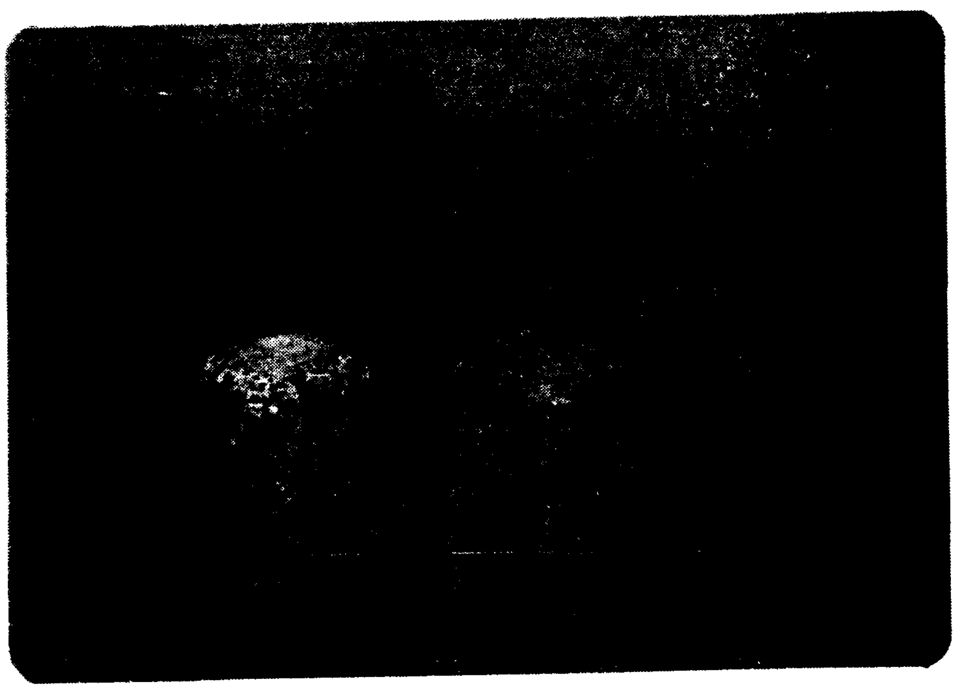

Figure 7 : Control specimens after 21 cycles of test.

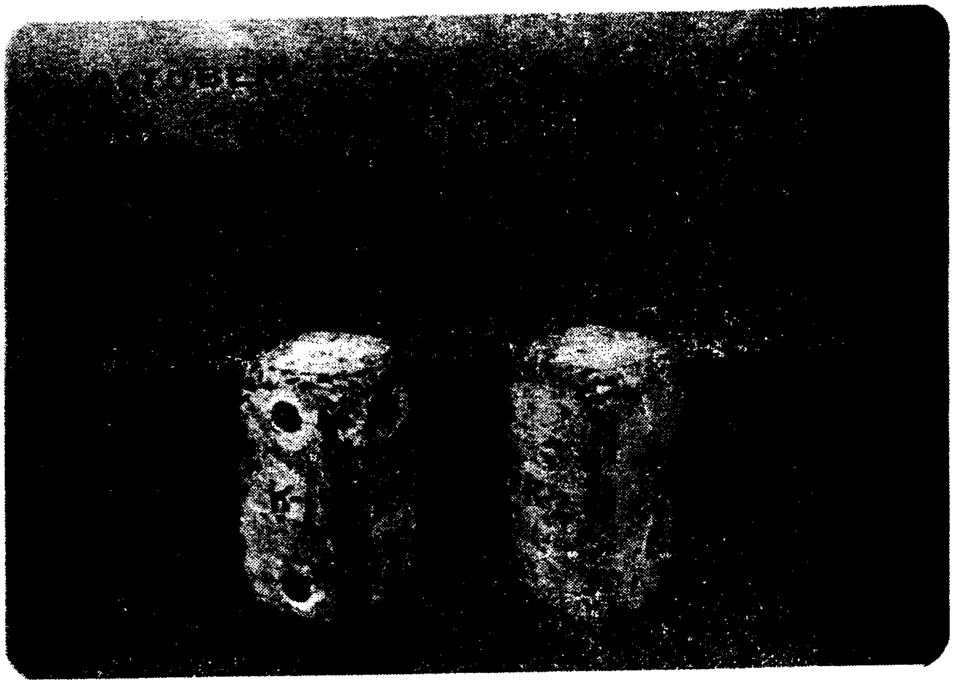

Figure 8 : Krystol-treated specimens after 21 cycles of test.

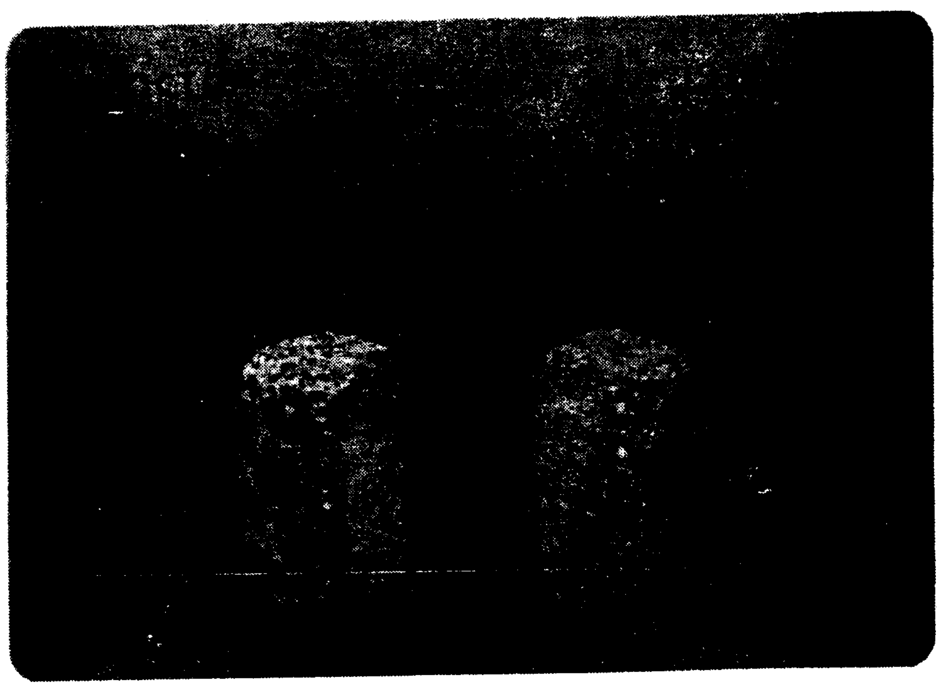

Figure 9 : Vandex-treated specimens after 21 cycles of test.

b) Strength

The results of compressive strength tests on concrete cylinders cast at the same time as the six prisms are given in Table 1. At the conclusion of the 21st test cycle, 2" square cubes were cut from the six prisms and tested in compression.

Table 1 : COMPRESSIVE STRENGTH DATA

| SPECIMEN | AVERAGE COMPRESSIVE STRENGTH $lb/in^2$ | |
|---|---|---|
| 4" DIA X 8" Concrete Cylinders continually Moist Cured. | 7 DAYS<br>4800 | 28 DAYS<br>6270 |
| 2" Cubes cut from Sulphate Test Prisms After Cycle 21 | 2" CUBE STRENGTH<br>$lb/in^2$ | EQUIVALENT 4" DIA X 8" CYLINDER STRENGTH<br>$lb/in^2$ |
| KRYSTOL | 7180 | 6460 |
| VANDEX | 6680 | 6010 |
| CONTROL | 5970 | 5370 |

From the results tabulated in Table 1 it can be seen that the "Krystol" treated concrete has suffered no apparent internal distress as a result of 21 cycles of sulphate attack. There is an indication of marginally reduced strength in the "Vandex" treated specimens, and significant strength reduction in the plain "Control" specimens. This indicates that "Krystol" treatment has reduced the potential for in-depth disruption of the concrete prisms.

c) Length Change

The results of length change measurements on the concrete prisms from cycles 1 to 10 are tabulated in Table A2 in the Appendix. Average results are graphically depticted in Figure 10. The trends established in the weight change measurements are closely paralleled in the length change determinations. i.e. the "Krystol" treated prisms show reduced length change relative to either the "Vandex" or "Control" prisms. This suggests that there is less formation of expansive disruptive products in the "Krystol" treated specimens.

The U.S. Bureau of Reclamation, in its accelerated sulphate resistance tests established as a criteria for failure of sulphate attacked concretes and expansion of 0.2% (2000 microstrain). It is clear that after

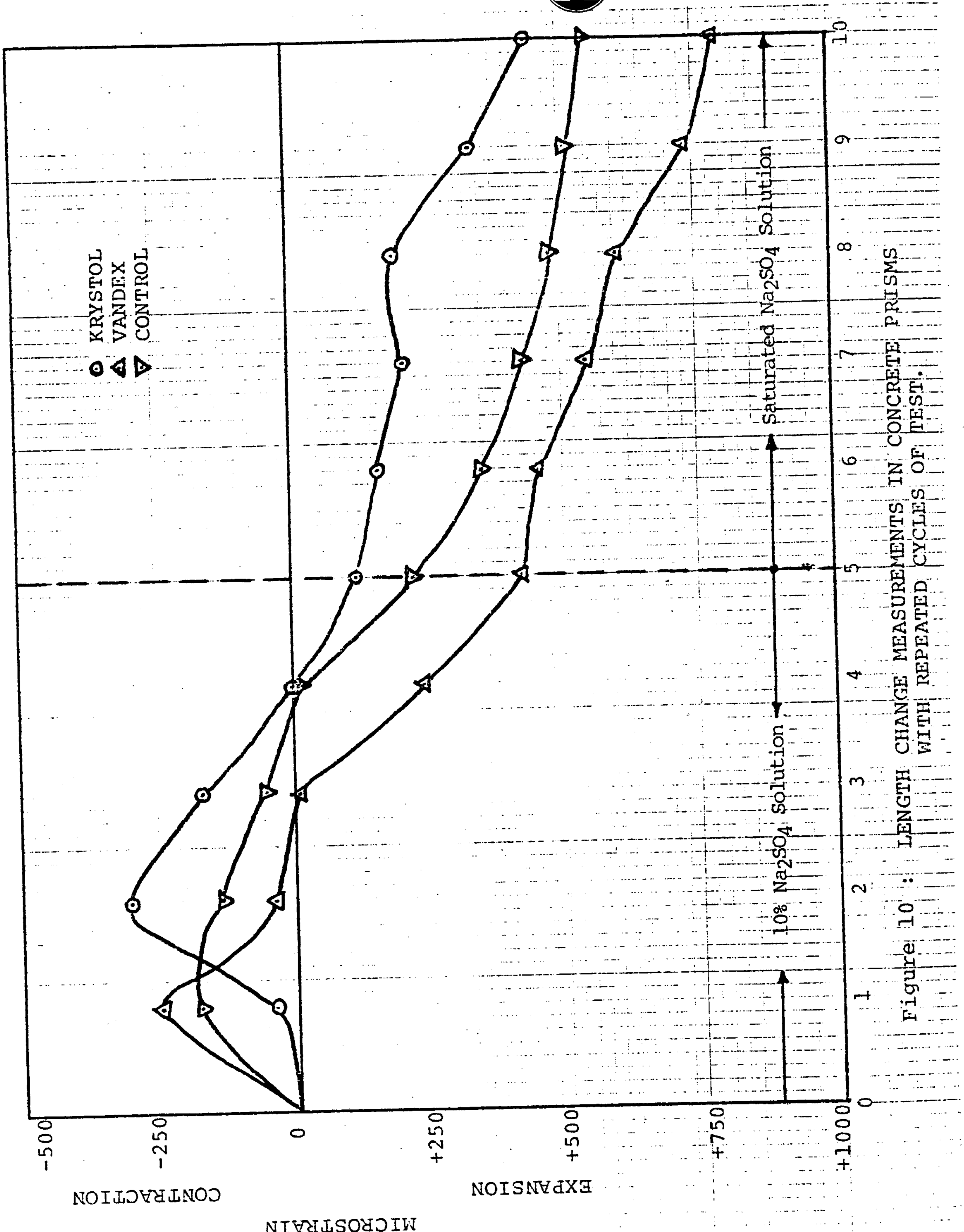


Figure 10 : LENGTH CHANGE MEASUREMENTS IN CONCRETE PRISMS WITH REPEATED CYCLES OF TEST.

10 cycles of test, none of the concrete samples examined in this investigation could be considered to have failed the criterion. The tests were continued past 10 cycles but are not reported because surface deterioration caused dislodgement of targets and unreliable results. Nevertheless, the improved performance of the "Krystol" treated prisms relative to the other specimens is well established.

## 5.) Conclusions

(i) "Krystol" treatment of concrete results in an in-depth penetration of the concrete pores, reducing the permeability and hence potential for attack from sulphate bearing waters.

(ii) Weight change measurements of "Krystol" treated concrete subjected to alternate cycles of soaking and drying in solutions of sodium sulphate showed that it had better resistance to sulphate attack than "Vandex" treated or plain concrete specimens.

(iii) Similarly, length change measurements indicated that "Krystol" treatment improved the resistance of concrete to the expansive disruptive action of sulphate bearing water.

(iv) Compressive strength determinations on cubes cut from prisms after 21 cycles of soaking in sulphate solutions and drying indicated no reduction in the internal strength of prisms treated with "Krystol". Significant strength reductions were noted in the plain "Control" concrete.

(v) For the structural grade of concrete tested (Type 10 cement, water/cement ratio 0.4, 28 day compressive strength 6200 lb/in$^2$) it could be expected that "Krystol" treatment of the concrete would prevent any significant surface attack from sulphates for about 8 to 15 years. Between 20 and 30 years, some minor surface deterioration, such as edge and corner erosion, and exposure of surface aggregates could be expected. Severe internal disruption and strength reduction of the concrete is not likely to occur in less than 30 years, and even after then "Krystol" could be expected to offer continued partial protection to the interior of the concrete.

R. M. HARDY & ASSOCIATES LTD.

Per: D. R. Morgan

D. R. Morgan, Ph.D.,
Materials Engineer.

DRM:sgm

Enclosures.

# APPENDIX

TABLE A 1 : WEIGHT CHANGE DATA

| CYCLE NUMBER | KRYSTOL | | | VANDEX | | | CONTROL | | |
|---|---|---|---|---|---|---|---|---|---|
| | K1 | K2 | K | V1 | V2 | V | C1 | C2 | C |
| 1 | 0.4021 | 0.0433 | 0.2227 | 0.3974 | 0.3057 | 0.3516 | 0.3179 | 0.1792 | 0.2486 |
| 2 | 0.4040 | 0.0433 | 0.2236 | 0.4856 | 0.4803 | 0.4830 | 0.3179 | 0.1792 | 0.2486 |
| 3 | 0.4021 | 0.2167 | 0.3094 | 0.4415 | 0.5677 | 0.5046 | 0.4995 | 0.2688 | 0.3842 |
| 4 | 0.4468 | 0.2167 | 0.3318 | 0.4415 | 0.6114 | 0.5264 | 0.5450 | 0.4032 | 0.4741 |
| 5 | 0.4435 | 0.2233 | 0.3334 | 0.6181 | 0.5240 | 0.5710 | 0.5904 | 0.4480 | 0.5192 |
| 6 | 0.5362 | 0.2167 | 0.3764 | 0.7064 | 0.5677 | 0.6370 | 0.5904 | 0.4480 | 0.5192 |
| 7 | 0.6702 | 0.3901 | 0.5302 | 0.7947 | 0.8297 | 0.8122 | 0.7266 | 0.4928 | 0.6097 |
| 8 | 0.6256 | 0.4335 | 0.5296 | 0.8506 | 0.8860 | 0.8683 | 0.8628 | 0.6720 | 0.7674 |
| 9 | 0.8043 | 0.6935 | 0.7489 | 1.0154 | 1.0044 | 1.0099 | 0.9083 | 0.8064 | 0.8574 |
| 10 | 0.8043 | 0.6502 | 0.7272 | 1.0154 | 1.0917 | 1.0536 | 0.9991 | 0.8512 | 0.9252 |
| 11 | 0.4468 | 0.4768 | 0.4618 | 0.8388 | 0.8734 | 0.8561 | 0.7720 | 0.5376 | 0.6548 |
| 12 | 0.4021 | 0.1734 | 0.2878 | 0.5298 | 0.1310 | 0.3304 | 0.6358 | 0.3584 | 0.4971 |
| | | | | | | | | | |
| 14 | 0.0 | 0.2209 | 0.1104 | 0.0 | 0.3954 | 0.1977 | 0.0451 | 0.0 | 0.0226 |
| 15 | 0.4915 | 0.6628 | 0.5772 | 0.2663 | 0.6590 | 0.4626 | 0.0451 | 0.0446 | 0.0448 |
| 16 | 1.6086 | 1.5024 | 1.5555 | 1.0652 | 1.6256 | 1.3454 | 1.7117 | 0.9375 | 1.0546 |
| 17 | 2.7256 | 2.0769 | 2.4012 | 1.8198 | 2.3286 | 2.0742 | 2.0730 | 1.7857 | 1.9294 |
| 18 | 4.8257 | 3.3142 | 4.0700 | 3.2401 | 3.3831 | 3.3116 | 3.8306 | 2.4107 | 3.1206 |
| 19 | 5.3172 | 3.3584 | 4.3378 | 3.9947 | 3.9104 | 3.9526 | 4.4164 | 2.9564 | 3.6814 |
| 20 | 5.7194 | 4.0212 | 4.8703 | 4.5717 | 4.1300 | 4.3508 | 4.6868 | 3.0357 | 3.8612 |
| 21 | 6.4790 | 4.7724 | 5.6257 | 5.1043 | 5.1845 | 5.1444 | 5.7684 | 3.1696 | 4.4690 |

NOTE: 1. VALUES TABULATED IN CYCLES 1 TO 12 REPRESENT % INCREASE IN WEIGHT RELATIVE TO THE ORIGINAL OVEN DRY WEIGHT OF SPECIMENS.

2. VALUES TABULATED IN CYCLES 14 TO 21 REPRESENT % DECREASE IN WEIGHT RELATIVE TO SPECIMENS BRUSHED TO REMOVE LOOSE MATERIAL AFTER CYCLE 13.

TABLE A 2 : LENGTH CHANGE DATA

| CYCLE NUMBER | KRYSTOL | | | VANDEX | | | CONTROL | | |
|---|---|---|---|---|---|---|---|---|---|
| | K1 | K2 | K | V1 | V2 | V | C1 | C2 | C |
| 1 | 0 | -75 | -38 | -375 | -125 | -250 | -175 | -288 | -232 |
| 2 | -488 | -112 | -300 | -75 | +12 | -32 | -138 | -225 | -182 |
| 3 | -250 | -88 | -169 | +12 | 0 | +6 | -100 | 0 | -50 |
| 4 | -225 | +225 | 0 | +488 | 0 | +244 | -125 | +150 | +12 |
| 5 | -62 | +300 | +119 | +562 | +288 | +425 | +185 | +275 | +225 |
| 6 | +162 | +175 | +168 | +625 | +288 | +456 | +425 | +275 | +350 |
| 7 | +100 | +325 | +212 | +550 | +550 | +550 | +662 | +188 | +425 |
| 8 | +175 | +212 | +194 | +625 | +588 | +606 | +712 | +250 | +481 |
| 9 | +225 | +450 | +338 | +662 | +825 | +744 | +762 | +275 | +518 |
| 10 | +338 | +550 | +444 | +688 | +875 | +782 | +825 | +288 | +556 |

NOTE: VALUES TABULATED REPRESENT LENGTH CHANGE IN MICROSTRAIN AFTER THE FIRST OVEN DRYING.