The Effect of High Temperature on the In-Situ Condition of PVC Waterstop

J. J. Deans, J. A. Sato, P. D. Bhat
Ontario Hydro, Ontario, Canada

ABSTRACT

The results of an experimental program investigating the effect of high temperature on some of the physical and chemical characteristics of PVC waterstop embedded in concrete are presented. In this program, PVC waterstop that had been embedded in concrete was exposed to a high temperature (60°C) for varying lengths of time. The findings of this investigation will be useful towards interpreting the leakage characteristics of concrete structures that contain PVC waterstop.

1.0 INTRODUCTION

Waterstops are used in concrete construction and expansion joints to prevent water or air leakage from the structure. Experience has shown that properly installed joints do perform effectively. However, a question as to the effect of high temperatures on the waterstop, with respect to any changes in its physical and chemical characteristics, and hence its performance as a barrier to leakage arises. In concrete structures, where their level of safety is of concern, the long-term reliability of joints containing waterstops is an important aspect to be considered.

In this paper the findings of an experimental investigation to determine the effect of high temperatures on changes in some of the physical and chemical characteristics of Polyvinyl Chloride (PVC) waterstop embedded in concrete are presented. The high temperature scenario that was considered is one in which the temperature inside the structure is 95°C while the external ambient temperature remains at 22°C. The resultant steady state temperature at the location of waterstop embedded in the structure's wall is expected to be approximately 60°C. The experimental scenario also included a variable exposure, to the 60°C temperature, that ranged from 3 days in duration to a maximum of 59 days.

2.0 BACKGROUND

It is well known that PVC waterstop exposed to high temperatures will undergo physical and chemical changes (e.g., volumetric reduction and plasticizer loss). The extent of these changes, however, in waterstop embedded in concrete is not well established. Data are available from experiments in which non-embedded waterstop was exposed to elevated temperatures up to 100°C for periods as long as 60 days (Cawthray, 1968). These tests concluded that the major effect of high temperature was a reduction in the waterstop's volume and mass, and that there was a linear relationship between these two quantities (Cawthray, 1968). Other data, from observations of PVC waterstop taken from actual hydraulic structures, after 12 and 20 years of service life, have also shown the occurrence of both volumetric and mass losses (Cordingley, 1983). These results indicate the potential significance that embedment may have in influencing changes, with time, of PVC waterstop. Therefore, the importance of this present investigation is in its consideration of both the effect of elevated temperatures and confinement on PVC waterstop.

3.0 EXPERIMENTAL WORK

The experimental work involved the testing of a series of specimens consisting of premeasured, short pieces (152 mm long) of 150 mm nominal width PVC waterstop embedded in 300 mm x 300 mm x 150 mm deep concrete blocks. Each waterstop sample was initially premeasured to determine its original dimensions (see Figure 1), volume, plasticizer content and Shore A hardness. The specimens, hereinafter referred to as plaques, were then placed in ovens and subjected to a temperature of 60°C for varying amounts of time. Additionally, non-embedded waterstop samples were suspended in air at the same temperature for comparison purposes. At selected intervals, plaques were removed from the oven and broken open. The waterstop samples were then remeasured at room temperature to determine if there had been any dimensional, volumetric, plasticizer content or Shore A hardness changes. The waterstop samples heated in air were also remeasured for these quantities, and then returned to the oven for further testing. The entire test duration was 59 days, with the first plaque being initially tested after 3 days of 60°C exposure, and with subsequent plaques being tested at 7 day intervals thereafter.

In order to obtain a quantitative assessment of the reliability of the results, two additional plaques were tested. For these tests, the two plaques were subjected to the same 60°C environment but for an arbitrarily selected duration of 38 days. This duration was selected on the basis of attaining 5% loss in volume, as was observed after 38 days of exposure to 60°C in the first series of tests (see Section 4). Therefore, in this second series of tests, it was the repeatability (or lack thereof) of volumetric shrinkage, as well as the other values being observed (i.e., changes in plasticizer content and hardness), that was being investigated.

4.0 RESULTS

For all waterstop samples, whether they were embedded in concrete (plaques) or suspended in air, there was a steady decrease in dimensions, volume, plasticizer content, and an increase in Shore A hardness as the duration of exposure to 60°C increased. However, a marked difference in the rate of change and absolute change of these properties was observed between the plaque waterstop samples and the waterstop suspended in air. For example, dimensional changes after the entire 59 day test period were, for the plaque waterstop samples, an average of -2.42%, -9.97% and -3.20% of their original length, width and thickness, respectively, as compared to changes of less than -0.25% in each of the three directions for the waterstop suspended in air (see Table 1). With respect to volumetric changes, there was a 6.2% decrease in the plaque waterstop's original volume after 59 days, whereas, for the same duration and for the waterstop samples suspended in air, there was only a 0.5% decrease (see Table 1). Volumetric changes for the full test duration are also shown in Figure 2. In this figure, the steady decrease in volume with time, which was still undiminished at the end of 59 days, for the plaque waterstop samples is in marked contrast to the very minimal loss of volume for the waterstop suspended in air.

Similar comparisons can be made for the other measured physical properties. Figure 3 shows a comparison of the changing plasticizer content for both types of waterstop samples. After 59 days, the plasticizer loss for the plaque waterstop samples was 33% of original content versus a 15% loss for the waterstop suspended in air. The Shore A hardness of the plaque waterstop samples rose from a value of 73 at the beginning of the test to a value of 88 at the end of the test. There was very little change in the Shore A hardness for the waterstop suspended in air.

With respect to the two additional plaques that were tested at 60°C for 38 days, the changes in volume of these waterstop samples have also been plotted in Figure 2. These samples experienced an average volumetric loss of 5.3% of original volume as compared to a volumetric loss of 4.9% of original volume for the plaque tested in the 59-day test series. A similar comparison for loss in plasticizer content shows that for the waterstop samples from both the 38-day test series and the 59-day test series each lost approximately 29% of original content at 38 days (See Figure 3). The Shore A hardness in the 38-day test series increased from 73 to 81, whereas, in the 59-day series, hardness increased from 73 to 85.

5.0 DISCUSSION

The PVC waterstop studied in this investigation underwent extensive changes after exposure to high temperature (60°C). It has been documented that for PVC, the rate of loss of plasticizer increases with increasing temperature and decreases with duration of exposure (Belcher, 1969). Loss of plasticizer will result in a loss in volume, mass, and dimension (i.e., shrinkage), as well as increased hardness (Belcher, 1969). It was observed in this investigation that these changes were significantly greater for waterstop embedded in concrete as compared to non-embedded. These differences are due to the coefficient of thermal expansion of the waterstop being much greater than that of concrete. In other words, upon exposure to an increasing temperature, the waterstop embedded in concrete goes into compression which drives out plasticizer and at the same time forces the waterstop into cavities of the concrete. Another implication of the difference in coefficient of thermal expansions is that since concrete is essentially incompressible relative to the waterstop, compressive forces can develop at the location of the waterstop, which in turn would produce a positive seal that would initially prevent leakage from occurring at the high temperatures. With increasing time and constant temperature, however, the amount of stress will decrease as the changes in the physical characteristics of the waterstop continue. This could eventually lead to the possibility of leakage upon cooling.

The effects of plasticizer loss and subsequent shrinkage upon cooling have never been related directly to leakage. However, it is apparent that as plasticizer is lost, shrinkage occurs which could lead to a gap between the waterstop and concrete. The reliability of concrete construction and expansion joints to act as air/water seals after exposure to high temperatures and subsequent cooling will probably be dependent on the propensity of the plasticizer to migrate and will be a function of the exposure conditions. If shrinkage is expected to be significant leading to a possible leakage path, the problem can be rectified by available repair techniques (Kostyk and Parnell, 1984).

6.0 CONCLUSIONS

When tested in an unstressed state at high temperature (i.e., 60°C) PVC waterstop had less mass, plasticizer and shrinkage losses when compared to PVC embedded in concrete. When high temperatures are applied to PVC waterstop encased in concrete, the higher thermal coefficient of expansion of the material causes the PVC to flow into voids in the concrete leading to a build up of compressive stresses. This increase in stress creates a positive seal which would prevent or reduce leakage when at high temperatures. Upon cooling, however, the waterstop will shrink. If shrinkage is significant, the problem can be rectified by utilizing available repair techniques.

7.0 REFERENCES

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ACKNOWLEDGMENTS

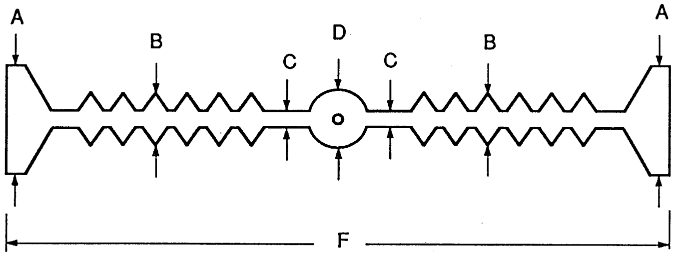
The investigation reported in this paper was fully funded by and conducted at the facilities of Ontario Hydro. The authors wish to express their appreciation for the support received.

TABLE 1

CHANGES IN WATERSTOP AFTER HEATING AT 60°C FOR 59 DAYS

PHYSICAL/ CHEMICAL CHARACTERISTIC	PERCENTAGE CHANGE	
	WATERSTOP EMBEDDED IN CONCRETE	WATERSTOP HEATED IN AIR
DIMENSION A	-2.98	+0.10
DIMENSION B	-2.43	-0.47
DIMENSION C	-4.33	-0.97
DIMENSION D	-2.93	-0.82
DIMENSION E	-2.42	-0.33
DIMENSION F	-0.97	-0.41
VOLUME	-6.27	-0.15
SHORE A HARDNESS	+21	+3
PLASTICIZER CONTENT	-33	-15

NOTES:
1) Percentage changes are referenced to the original values recorded at the start of the tests.
2) All measurements were conducted at room temperature.
3) See Figure 1 for a description of each dimension.



DIMENSION A: Across the end ribs
DIMENSION B: Across the inner ribs
DIMENSION C: Across the thickness
DIMENSION D: Across the centre bulb
DIMENSION E: Length of specimen (not shown)
DIMENSION F: Width of specimen

NOTE: Average values for each dimension were determined by repeating a measurement three times at three locations along the length of the specimen (i.e., nine measurements total).

FIGURE 1
DIMENSIONAL MEASUREMENTS

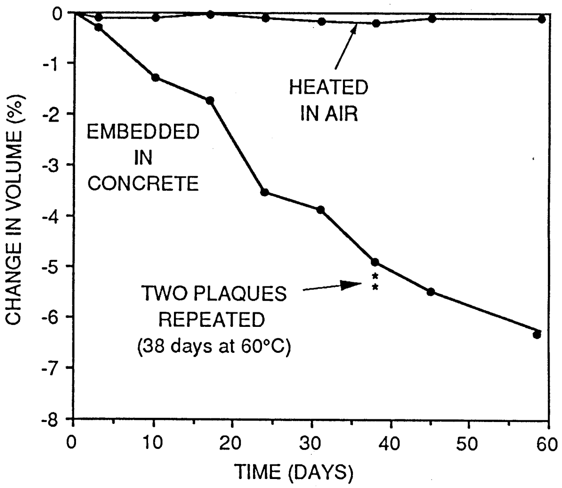


FIGURE 2
VOLUMETRIC CHANGES

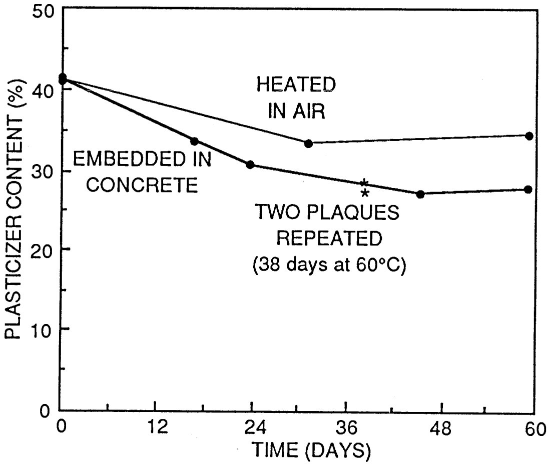


FIGURE 3
PLASTICIZER CONTENT