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# Drying Effect of Normal and High Strength Concrete Cylinders with Different Sizes

Sıddık ŞENER [1♠], Hikmet Duygu ŞENER [2], Varol KOÇ [3]

[1] *Gazi University, Faculty of Engineering and Architecture, Department of Civil Engineering, 06570 Ankara, Turkey*
[2] *Formerly MSc student of Structure Education Division of Gazi University, 06570 Ankara, Turkey*
[3] *19 May University, Faculty of Engineering, Department of Civil Engineering, 55139 Samsun, Turkey*

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**ABSTRACT**

This paper is a report on a study of shrinkage-weight loss relationships for normal and high strength concrete specimens of different sizes. The maximum aggregate size used in concrete mixes was 10mm. Three geometrically similar test specimens of a cylindrical shape with diameters of 37.5 mm, 75 mm and 150 mm and a height/diameter ratio of two were used in the experiments. All specimens were subjected to standard air drying in a temperature and humidity controlled laboratory (average relative humidity 50±6% and temperature 17±1$^0$C) for a period of 60-70 days. Weight loss and shrinkage measurements were conducted on the specimens prepared with normal and high strength concrete. Results indicated that the time required for the same weight loss ratio was found to be about 7.4 and 8.5 times longer for the largest specimen size than the smallest specimen for normal and high strength concrete respectively.

**Key Words**: Concrete, Drying, Measurements, Moisture, High strength concrete, Weight loss.

## 1. INTRODUCTION

The use of concrete, especially high strength concrete (HSC), is growing steadily throughout the world. In parallel with this growth, there has been a widespread research interest in characterizing the properties and performance of HSC [1]. As confidence in the material is established and its economic potential is appreciated, it is likely that the construction industry will further make use of this material.

The relationship between weight loss and drying shrinkage has been well established for normal and high strength concrete. The main goal of this paper, based on short time (about two months) air drying effects, is to expand on earlier work [2] on shrinkage-weight loss relationship and include specimen size effect.

## 2. WEIGHT LOSS AND SHRINKAGE

The easiest way to get information on the shrinkage of concrete is to measure the weight loss of a specimen exposed to a controlled drying environment [3]. Shrinkage of concrete is a phenomenon resulting in a reduction in volume, although it is normally determined by measuring the reduction in length. Four principal mechanisms (capillary tension, surface tension/surface energy, disjoining pressure and movement of interlayer water) have been proposed for describing shrinkage and swelling in cement pastes. The shrinkage of hardened concrete due to drying is called the 'drying shrinkage' while 'plastic (autegenous) shrinkage' is used to describe the shrinkage of fresh concrete [4]. The 'autogenous shrinkage almost uniformly occurring inside a specimen is different than the drying shrinkage which is not uniform.

♠Corresponding author, e-mail: siddik@gazi.edu.tr

Drying shrinkage of concrete is caused primarily by the contraction of the calcium silicate (CSH) gel in the hardened cement paste when the moisture content is decreased. The extent of shrinkage depends on many factors, including the properties of the materials, the temperature and relative humidity of the environment, the age of specimens when the concrete is subjected to the drying environment, and the size of the structure or member. Most shrinkage studies have been carried out in laboratories kept at constant temperature and relative humidity. It is important to note that such conditions are significantly different from those encountered by concrete subjected to natural environmental conditions.

The relationship between shrinkage and weight loss due to drying has already been well established for normal strength concrete [5]. However, the limited research results available in the literature [2, 6] show that the drying shrinkage-weight loss relationships are almost linear, as observed earlier for normal strength concrete. The shrinkage is proportional to the water content within the range 150-230kg/m$^3$ [2].

The low initial water content and low intrinsic vapor permeability of HSC results in drying shrinkage being less than in normal strength concretes, whereas autogenous shrinkage is more significant [7]. The combination of low water content and the addition of micro silica lead to self-desiccation, and shrinkage is induced when there is insufficient water available for continued hydration [2]. Although it is possible to separate the autogenous shrinkage from the drying shrinkage by wrapping the test specimen to eliminate water loss, this was not done in this case since the objective was to study the actual shrinkage values obtained under controlled environmental conditions for a range of different sizes.

## 3. TEST SPECIMENS AND EXPERIMENTAL METHOD

The results reported here were obtained from a study conducted with cylindrical specimens of two practical concrete mixes with normal and high strength. Ordinary Portland cement (PKC/B 32.5R according to Turkish Standard 12143) similar to ASTM Type I, was used throughout the investigation. The coarse aggregate was obtained from sieve No: 3/8" (maximum aggregate size $d_{max}$=10 mm), and fine aggregate was obtained from sieve No: 4 (maximum sand size $d_{max}$=5 mm) which means that the concrete used here was not micro concrete but real concrete. Aggregate was obtained from the Sakarya River in Kazan. The silica fume used has a trade name 'Sikafume HR' and was added to the mix in the form of powder. A polynaphthalene sulphonate based admixture (Sikament-300) was used as the superplasticizer (SP) to achieve adequate workability in the high performance mixes.

The mixing was carried out in a horizontal rotating pan and paddle type mixer and a consistent procedure was maintained throughout the study. The cement with silica fume and sand were initially mixed together and thereafter the water and coarse aggregate were added. Towards the end of the mixing period, sufficient SP was added to the mix to achieve the required workability.

The test specimens were cast in steel moulds with compaction being achieved via a vibrating table. Upon compaction, the specimens were covered immediately with moist hessian and polythene sheets, until they were demoulded the following day. Immediately after demoulding, pair of DEMEC (demountable mechanical strain gauge) pips was established on the specimens by means of "plastic padding" adhesive, as illustrated in Figure 1. Then, the specimens were transferred to the control room which was kept at constant environmental conditions (average relative humidity=50±6% and temperature=17±1$^0$C). According to ASTM 4% variance at the relative humidity change is 12%. Effect of this difference was ignored, because all the specimens were kept at the same environmental condition. The size of the smallest specimen (37.5×75mm) was smaller than the range of shrinkage measurement of the 100mm DEMEC gauge available in our laboratory; and, therefore, no shrinkage measurements were made with the smallest specimen. For the measurement of shrinkage the DEMEC pips fixed only to one specimen N4 for normal and H2 for high strength concrete.

The use of ratio of the biggest to smallest specimen size was 4 necessary to obtain cylinder dimensions could be handled with the laboratory equipment available. For each of the three different specimen sizes, three replicate cylinders with normal strength and three replicate cylinders with high strength were tested. This made a total of 3×3×2=18 cylinders.

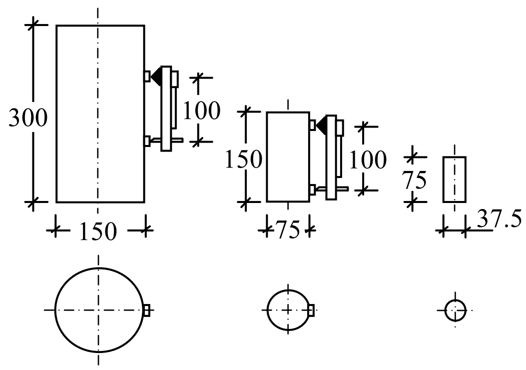


Figure 1. Test specimens for different sizes (mm).

The initial weight and gauge lengths of each test specimen were determined immediately after the DEMEC pips had been established on one specimen for each strength. Thereafter the shrinkage and weight loss reading were taken in constant logarithmic time intervals. The readings were gradually reduced as the specimens matured. At least three readings were taken on each pair of pips, the average values then recorded. All the specimens were kept in the control room for the period of 70 days for normal strength, 60 days for HSC, after which most of the weight loss had taken place for each time period.

The cylinders were similar in three dimensions, which means that the cylinder diameter ($D$) were all proportional to the length of cylinder ($L$). Three specimen sizes, had the cylindrical diameter of $D$=37.5 mm, 75 mm and 150 mm. For all cylinders, the ratio of the length to the diameter of cylinder was $L/D$=2. Three identical specimens were cast for each size and two types of concrete.

The concrete mix proportions for the two mixes are given in Table 1 (by weight). All the specimens of all the sizes and types were cast from the same batch of concrete in order to minimize statistical scatter in the results.

## 4. TEST RESULTS AND THEIR ANALYSIS

The corresponding weight loss-time responses, during the 70 days of drying, for the normal strength concrete, is shown in Figure 2; during the 60 days of drying for the HSC is shown in Figure 3 ($t_0$=initial time of test, $t$=any time). The weight loss is expressed as a percentage of initial weight of the test specimens. The progress of drying for tests for the 75×150 and 37.5×75 mm specimens was monitored by weight measurements on an electronic precision balance whose resolution was 0.01 N and maximum capacity 20 N. Furthermore, the accuracy of the weight loss results for these larger cylinders was limited due to the sensitivity of the weighing machine available in the laboratory. The weight of the 150×300mm cylinders` results was obtained with a mechanical balance (Trade name OHAUS, 200 N capacities with 0.01 N precision).

The main conclusion to be drawn from the weight loss-time relationships is that the results for the normal and HSC mixes are remarkably similar for the tested specimen sizes. It can be observed from Figure 2 and 3 that the weight loss is reduced significantly as the specimen size is increased, as expected. The size of the test specimen affects the weight loss development due to the variation in the length of the drying path which, in turn, affects the time required and the quantity of water migrating from the test sample.

The reduction in weight loss as the strength of concrete is increased is brought about by a number of factors. The main contributing factor is the amount of original water content in each mix. In the case of normal strength concrete, a larger amount of absorbed and evaporable water is available, which tends to increase the drying response. However, the thickness of the absorbed water layer is smaller in the case of HSC resulting in a decrease in water diffusion. Furthermore, the expulsion of moisture from the gel to pores becomes more difficult and porosity and water content are decreased. In addition, the pore refinement caused by the addition of silica fume in HSC mixes leads to low diffusibility [2].

The evolution of the weight loss for the three specimen sizes is shown in Figures 2 and 3 by data points in actual time. The dashed curve in these figures represents the average values for the three smallest size specimens and the solid curve represents the average for the three biggest size concrete specimens. Note that despite statistical scatter, each small specimen was drying faster than any of the big size specimens. The difference between the mean weights of the three sets of specimens is significant but not very large.

In Figures 2 and 3, $t$ is time, $\phi$ is the coefficient indicating the ratio of increase of weight loss. For simplicity, we will assume that the coefficient $\phi$ has approximately the same value for all points of the specimen during the initial drying period. This could be accurate only at the very beginning of drying, there is no doubt that appreciable nonuniformities in the distribution of $\phi$ will develop later. Lacking more sophisticated test results, we have to content ourselves with assuming the coefficient $\phi$ to be approximately uniform and constant throughout the specimen.

Introduce new time $\theta$ such that $\theta=\phi t$. Thus, the curves of weight loss should be identical when plotted versus $\theta$ rather than $t$. The coefficient $\phi$ may be determined as follows: (1) Plot the curves of specific weight loss (i.e., total weight loss of the specimen divided by specimen weight) versus log$t$, and determine the mean curves for the specimens biggest and smallest size (see the solid and dashed curves in Figure 2b, and Figure 3b); and (2) nothing that $\log \theta = \log\phi + \log t$, the value of $\log\phi$ represents the mean horizontal distance between these two curves in the initial drying period (i.e., up to about 50 days). The distance $\log\phi$ is marked in Figure 2b and Figure 3b. In this manner, it is found from Fig.2b that $\phi$=7.4 is for normal strength and $\phi$=8.5 is for high strength concrete.

After this initial period, the weight curves in the actual time are approximately parallel with a constant time lag for the same weight loss, which means that the ratio of corresponding time between small and large specimens is decreasing. This behavior may be explained by the fact that in the second drying period (after about 10 days for Figure 2) the moisture within the specimen is almost in equilibrium with the environment. By contrast, in the initial period water migrates towards the drying face through the concrete. This indicates that the rate of drying in the specimens should initially be higher, as is seen on the weight curves.

Figures 2b, 3b shows the weight loss results plotted against the corresponding log time for both normal (Figure 2b) and high strength (Figure 3b) mixes. It is important to note the significant reduction in the weight loss scale as the specimen size is increased. The slope of the graphs is steeper in the case of the normal strength results, which simply reflects the variation between normal and HSC mix.

Table 1. Mix proportions (by weight).

| Specimen | Cement | Silica fume | Fine agg. | Coarse agg. | Water | Superplas. | Comp.Strength[1] MPa |
|---|---|---|---|---|---|---|---|
| Normal strength | 1 | - | 2 | 2 | 0.5 | - | 22 |
| High strength | 1 | 0.11 | 1.4 | 1.7 | 0.4 | 0.0084 | 34 |

[1]Potential compressive strength of this mixture was obtained from previous study [8]

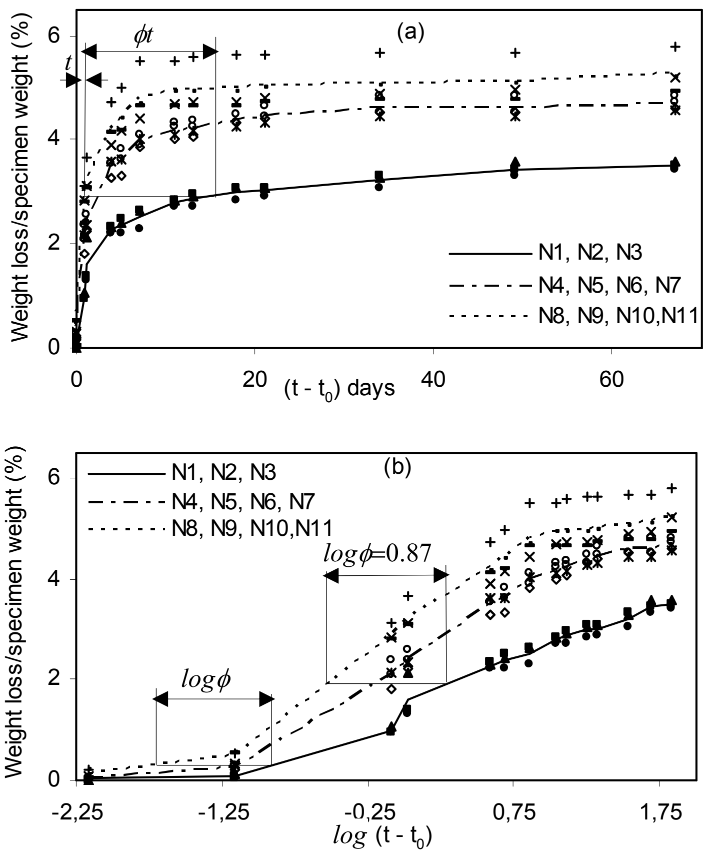


Figure 2. a) and b) Effect of size on weight loss with normal strength.

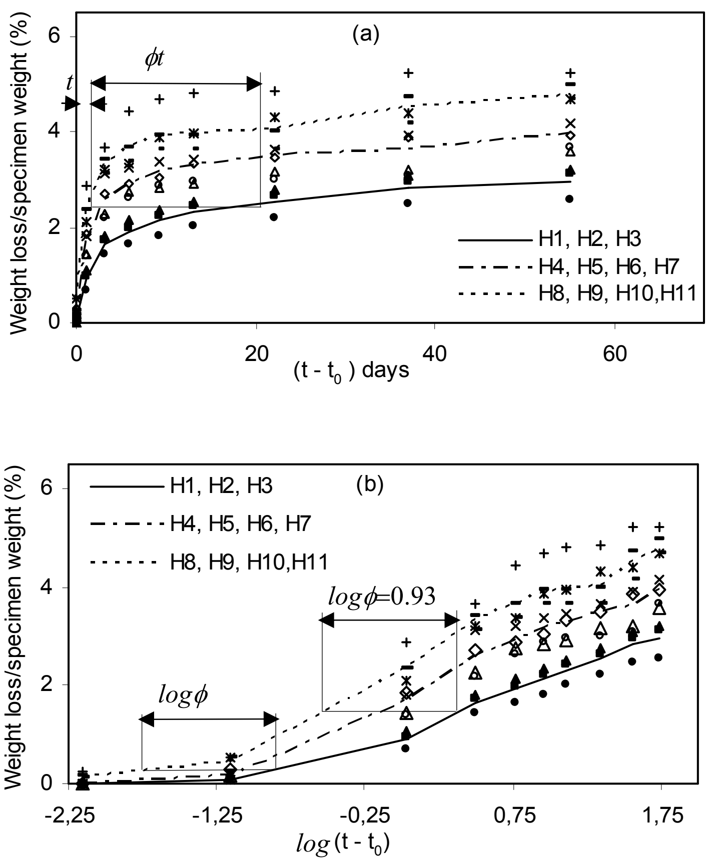


Figure 3. a) and b) Effect of size on weight loss with HSC.

The shrinkage-time responses, developed over a period of 50 days for normal strength and 40 days for high strength under standard environmental drying conditions, are shown in Figure 4a. It is better to use for long specimen long demec gage, for short specimen short demec gage. In this study for two different sizes only one size (100 mm) DEMEC gage was used. Figure 4a shows that shrinkage is more significant during the early stages of drying. This is important, since this period is the most crucial in terms of reducing early age cracking at the time when the strength of the concrete is being developed.

The same general conclusions can be drawn from these results, i.e., the influence of size is more effective during the early stages of shrinkage strains. The overall trend of the shrinkage-time curves for the concrete mix shown in Figure 4a is similar; there is more rapid increase in shrinkage during the early days followed by a more steady increase in shrinkage beyond 30 days in the case of the normal mixes. This effect is more apparent in the case of the smaller test specimens, indicating that early autogenous shrinkage takes place in the HSC mixes. It was observed that approximately 80% of the 50 days` shrinkage values occur during the first month of drying in the case of normal strength.

Figure 4b shows the shrinkage results plotted against the corresponding weight loss for the normal (N4) and high (H2) strength concrete and specimen size. Only two results obtained from H2 (150×300 mm) and N4 (75×150 mm) cylinders are reported here. It was observed that an approximately linear relationship (for the time period of 40 days) is displayed between shrinkage and weight loss which is agreement with earlier published results [9, 10]. Figure 4b summarizes the shrinkage-weight loss relationships observed during the first 40 days of drying. The authors are currently considering this linear relationship for use in developing long-term prediction models from short-term tests. However, the authors are aware of the fact that this approximation will underestimate long-term shrinkage. Full details regarding the test results are presented in an internal report [11].

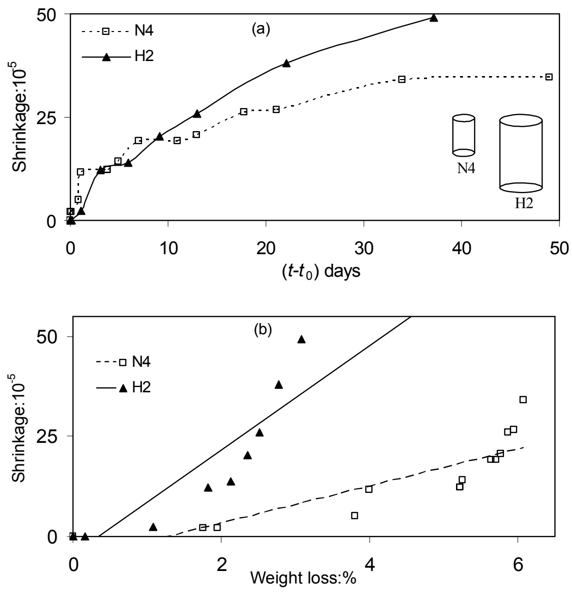


Figure 4. For HSC and normal strength cylinders, a) Effect of shrinkage, b) shrinkage-weight loss relationship.

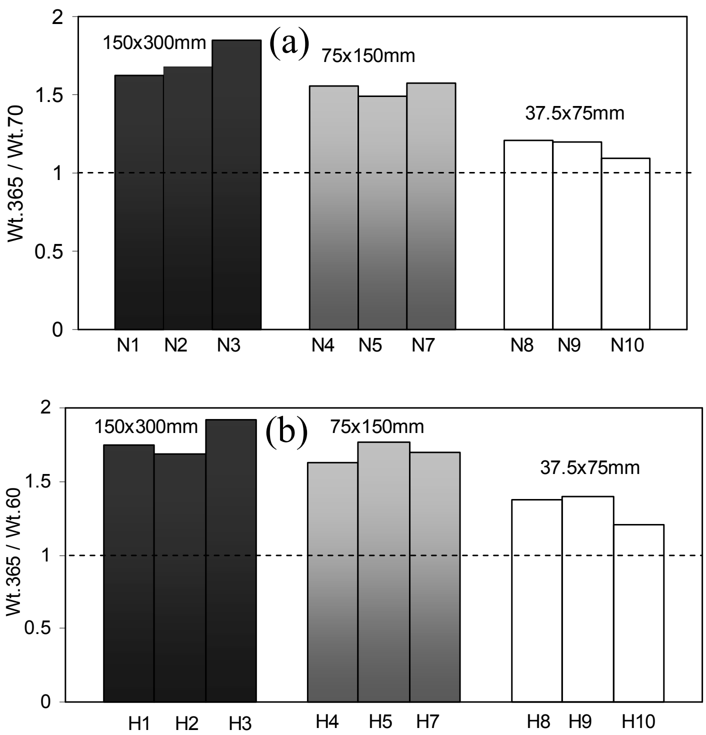


Figure 5. Comparison between long and short term results of weight loss a) for normal strength, b) for HSC.

Table 2. Measured axial peak after oven and calculated nominal stress for various sizes of cylinders.

| Specimen No | *D* (mm) | *L* (mm) | Failure loads after oven (kN) | Stress (MPa) |
|---|---|---|---|---|
| N1 | 150 | 300 | 269.8 | 15.3 |
| N2 | 150 | 300 | 286.5 | 16.2 |
| N3 | 150 | 300 | 212.9 | 12.1 |
| N4 | 75 | 150 | 59.5 | 13.5 |
| N5 | 75 | 150 | 56.2 | 12.7 |
| N6 | 75 | 150 | was not in oven dried | |
| N7 | 75 | 150 | 51.1 | 11.6 |
| N8 | 37.5 | 75 | 9.4 | 8.5 |
| N9 | 37.5 | 75 | 8.5 | 7.7 |
| N10 | 37.5 | 75 | 10.8 | 9.8 |
| N11 | 37.5 | 75 | was not in oven dried | |
| H1 | 150 | 300 | 287.4 | 16.3 |
| H2 | 150 | 300 | 367.9 | 20.8 |
| H3 | 150 | 300 | 372.8 | 21.1 |
| H4 | 75 | 150 | 50.4 | 11.4 |
| H5 | 75 | 150 | 105.1 | 23.8 |
| H6 | 75 | 150 | was not in oven dried | |
| H7 | 75 | 150 | 88.7 | 20.1 |
| H8 | 37.5 | 75 | was not in oven dried | |
| H9 | 37.5 | 75 | 16.2 | 14.7 |
| H10 | 37.5 | 75 | 8.0 | 7.2 |
| H11 | 37.5 | 75 | 16.9 | 15.3 |

## 5. SHORT-TERM AND LONG TERM WEIGHT LOSS

The weight loss-time graphs (Figures 2, 3) imply that the most of weight loss had occurred during the first 70 days period after the specimens were oven dried at $105^0$C for 24 hours. This work is done in order to determine the remaining water which could be extracted from the specimens.

The long lasting plateau region in the weight loss-time graphs (Figures 2, 3) suggested that most of the weight loss should have occurred during the first 70 day period. However, oven dried results indicated a major additional weight loss amounting to 70-80% in the case of the largest specimen as shown in Figure 5 which present the results for the long/short term weight loss ratios.

Two trends are apparent in the results shown in Figure 5. Firstly, a significant amount of additional weight loss takes place between 70 days and oven dried results. This additional weight loss for the biggest specimen approximately is on the order of 70% for the normal strength with an increase to around 80% for the high strength; for the smallest specimens, 20% for the normal strength, with an increase to around 25% for the high strength. Secondly, in most cases, it is observed that the high strength mixes display a greater increase in weight loss between 70 days and oven dried results than the corresponding normal strength concrete. This supports the results shown in Figures 2, 3 which show that the effectiveness of high strength concrete weight loss diminishes with time. Long term weight loss was found to be greater in a high strength concrete with bigger size than the normal strength concrete with small size [2].

At the end of weight loss tests, all the cylinders were tested under the axially loaded compression force. The compressive test results of cylinders after oven drying were given in Table 2. The measured compressive stresses were generally lower for smaller sized specimens which are in contrast to a size effect analysis given in literature [12, 13]. The main reason for this contradiction may be due to the experimental conditions of this study in which the tests were started just after demoulding of specimens and the specimens were not cured in a water bath. The other reason, that of the very low compressive strength for the oven dried small specimens, may be due to extensive cracking when the cylinders were subjected to $105^0$C for 24 hours.

## 6. DISCUSSION

The shrinkage-weight loss relationship produces a curve as shown in Figure 4b which can be divided into two phases. The initial phase is a linear line with a small slope. The last phase is a concave curve. This pattern was observed in two specimens. Despite the actual curve behavior of the shrinkage-weight loss relationship is a reasonable as a first approximation for the whole range covering the two phases.

The measuring length was limited so to eliminate end effects, measuring range is at least the length of thickness far from the end to avoid end effects, but here not accounted. Also, it is better to do similar tests for different geometry such as cubs, prisms etc.

## 7. CONCLUSIONS

Based on the results of this limited time experimental results, the following conclusions are drawn:

1. For all sizes, weight loss and shrinkage curves appear to have a somewhat reducing rate with increasing time. For the same weight loss being about $\phi$=7.4 times larger for the smallest size (37.5×75mm) than the biggest size (150×300mm) specimen for normal strength and $\phi$=8.5 for high strength concrete.

2. It is observed that an approximate linear relationship is displayed between shrinkage and weight loss. The linear relationships are valid only within this time scale and the results should not be extrapolated beyond this limit.

3. A Significant amount of additional weight loss takes place between 70 days and oven dried results. This additional weight loss for the biggest specimen approximately is 70-80%, for smallest specimens around is 20-25%.

4. The weight loss ratio for the oven-dried high strength concrete is appreciably higher than that for oven-dried normal strength concrete, while no significant difference exists for the 70 days drying of the normal strength and high strength concretes.

5. Failure loads of oven dried specimens did not show the size effect which is big specimens gives big failure stress than small sizes. It is not valid for without oven dried specimens.

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