

# Shrinkage and Weight Loss Development for Normal Strength Concrete

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## Abstract

The paper presents outputs from an investigation carried out to study the relationship between drying shrinkage and weight loss of plain normal strength concrete (NSC). Two crushed limestone aggregate concrete mixes of grade 40 and 60 MPa had a water /cement ratio (W/C) 0.56 and 0.5 respectively were tested. In addition two other identical gravel aggregate concrete mixes also tested (Limestone and Gravel denoted in this paper results by L and G respectively). The maximum aggregate size used in all concrete mixes was 14mm. All specimens were subjected to standard air drying in a temperature and humidity controlled room (RH 65±5%, and temperature of 20±2C°) for 100 days. The test specimens were dried by an oven to 105 ± 5°C, after the 100 days regime terminated and the final values for shrinkage and weight loss reported. It was found that shrinkage and weight loss had an approximately linear relationship in the experimental period considered, and similar behaviour for both gravel and limestone aggregate was observed.

It was also observed that the moisture loss by oven drying had increased with direct relation to specimen size, but the shrinkage results are comparable to that of air drying and slightly affected by the specimen size.

## 1 Introduction

Concrete is subjected to change in volume during and after hardening period. This dimensional instability is of considerable importance to the construction industry. In practice, deformation are partly or wholly restrained, and therefore they induce high tensile stress , if excessive can result cracking which produce poor performance concrete, and that may significantly reduce the safety margins against some types of collapse and so a major effect on the

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durability of concrete is achieved (Hobbs,1977, pp 70-80). Many factors may cause volume change of concrete,if we consider moisture content deformation out of the application of load at constant temperature and relative humidity, concrete can undergo either “ Shrinkage “, or expansion “ Swelling “ due to losses or gain of moisture respectively. Shrinkage of concrete is a complex phenomenon resulting in reduction in volume, although it is normally in practice both shrinkage and swelling measured simply as a linear strain (mm/mm), expressed in millionth ( $10^{-6}$ ). Four principle 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 (Kenji, 1983, pp 216-224). The shrinkage of hardened concrete due to drying is referred as “drying shrinkage” while “plastic shrinkage” is used to describe the shrinkage of fresh concrete. The relative contribution of autogenous shrinkage to total shrinkage strain increases as the grade of concrete increases (Hobbs, 1971, pp 89-98). Shrinkage as described in this paper is the strain in unstressed hardened concrete due to moisture loss caused by drying under constant temperature and relative humidity. It is well known that shrinkage of concrete is related to moisture loss, which is due to drying and that relation for NSC was established by number of workers (Terrill et.al.1986 pp 220-225). For example some results, shows that weight change decreased markedly with increasing specimen size, increasing curing period and decreasing W/C ratio, and the relation between shrinkage and weight loss was established as a linear in some regions before the effect of carbonation occurred (Mears and Hobbs, 1972, pp 77-83). Other results (Hansen,1987, PP 323-328), observed an approximate straight line relation between shrinkage and weight loss, by which it was suggested that the observed relation can be used to predict shrinkage values, and similar results confirmed by others (Campbell, and Rogers, 1975, PP 193-202). Other researches (Almudaiheem, and Hansen, 1987, PP 130-135), reported on the possibility to update shrinkage prediction models such as RILEM prediction model (B3), using shrinkage weight loss data. Although of the numerous studies have been addressed the drying shrinkage of NSC but still the problem of prediction of long term shrinkage requires more improvement to reduce the uncertainty and gives

more reliability for structural and design engineers. This paper is aimed to demonstrate the contribution of specimen geometry, concrete grade and aggregate type in shrinkage weight loss relationships for NSC in a period of 100 day of drying. From the other hand, results obtained from this and other studies will enhance ongoing efforts to update and improve the prediction accuracy of some common available shrinkage prediction models.

## **2 Experimental details**

### **2.1 Materials and mix proportions**

The results reported here form a part of study conducted to study the time-dependent properties of both NSC and HSC, using locally supplied ingredients (El-Baden, 2000, pp489). Initially four concrete mixes with medium to high workability were developed with nominal 28-day cube compressive strength of 40 and 60 MPa. Ordinary Portland cement (Class 42.5N) confirmed with BS 12 (British Standard Institute, 1991), and normal water tap were used in all targeted mixes. Cement content of 400Kg/m<sup>3</sup> was used for all mixes. Saturated surface dry, rough and irregular crushed limestone and natural gravel aggregates with maximum size of 14mm both confirmed with BS 882 (British Standard Institute, 1983), were used throughout the investigation. Each kind of aggregate was used in two identical mix proportions, as shown in Table 1. Some of their physical properties presented in Table 2. Natural beach sand of maximum particle size of 2mm, confirmed with BS 882 (British Standard Institute, 1983) was used. All mixes were performed using an electrical horizontal pan mixer and standardised mixing procedure was used. Control test specimens were taken at this stage, to ensure the repeatable mixes had been achieved. Routine workability tests such as slump were carried out upon completion of the mixing process, (See Table 1).


**Table 1. Mix proportions**

Grade (MPa)	Mix Proportions ( by mass )				Slump (mm)
	Cement	Sand	Coarse Agg.	Water	
( I )-Limestone Aggregate					
40	1	2.00	2.50	0.56	150
60	1	1.81	2.81	0.50	100
( II )-Gravel					
40	1	2.00	2.50	0.56	250
60	1	1.81	2.81	0.50	150

**Table 2. Some physical properties of coarse aggregate**

Coarse Aggt. Type	Specific Gravity	Bulk Density ( kg/m <sup>3</sup> )	Water Absorption	Voids Volume
			( % )	
	2.67	1557	1.46	41
Gravel	2.66	1521	1.49	42.8

## 2.1 Preparation of test specimens and curing conditions

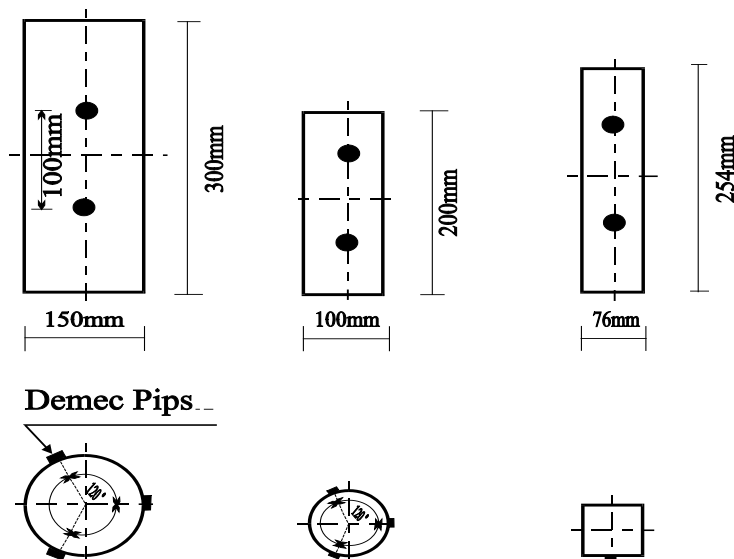


The control test specimens (to determine compressive, flexural and splitting tensile strengths at 28 days) and the shrinkage test specimens were cast in steel moulds with compaction being achieved via a vibrating table. Upon compaction, the specimens were covered immediately with moist hessian and polythene sheets, until they were demoulded the following day. The control specimens were immediately placed under water until they were required for testing at 28 days. Immediately after demoulding, the shrinkage specimens, illustrated in Figure 1, had Demec pips fixed by means of “plastic padding” adhesive and thereafter were transferred to the control room which was kept at constant environmental conditions (RH 65±5%, and temperature of 20±2C0). Two 76x76x25 mm prisms, two 100x200 mm cylinders and two 150x300 mm long cylinders were prepared from each mix. For all samples the gauge length for determining shrinkage was 100 mm as illustrated in Figure 1.

## 2.2 Instrumentation and testing procedure

The initial weight and gauge lengths of each test specimen were determined immediately after the demec pips had been established. A demec mechanical strain gauge confirmed to BS 1881 (Morice, and Base, 1953, PP 37-42), having gauge lengths of 100 mm and an accuracy of 0.002 mm per division was used for the shrinkage-strain measurements. A balance scale with an accuracy of 0.01 gm and maximum capacity of 4 kg was used for weighing the prisms and plate-form scale balance had a maximum capacity of 31 kg and an accuracy of 0.5 gm was used for the cylinder samples. Both the strain gauge and weighing scales were kept all the time along-side the samples in the humidity and temperature control room, to avoid any errors in the readings due to temperature or humidity change. Thereafter the shrinkage and weight loss readings were taken daily with the frequency of the readings being gradually reduced as the specimens matured. The readings were taken according to the following schedule: Once a

day for the first 4 days, at the end of the first week, at 10 days, at 2 weeks, at 20 days, and then once every 10 days up to 100 days. Two or three readings were taken on each pair of pips in millionth ( $10^{-6}$ ), and the average values recorded. The cylinder shrinkage was taken as the average value recorded on the three gauge lengths, distributed at  $120^\circ$  from each other. In the case of weight loss, the results were expressed as a percentage of original weight of the cylinders. All specimens were kept in the control room for a period of 100 day by which time most of the drying shrinkage had taken place. After the 100 days terminated the shrinkage samples were dried in an oven to  $105 \pm 5 C^\circ$ , until approximate weight loss equilibrium was attained (Soroka, 1979), and then the ultimate weight loss recorded; subsequently the samples transferred to air tight cooling desiccator for 24 hours in-order to take final shrinkage measurements. Table 3 presents sample of results.



**Fig. 1. Shrinkage and weight loss samples**

Table 3. Sample of ultimate shrinkage (Standard & oven)

Type of aggregate	Time Days	Cylinder ( 100x200)			
		40 MPa		60 MPa	
		Sh.	$\Delta$ wt. %	Sh.	$\Delta$ wt. %
Limestone	100	441	2.242	391	1.437
	Oven	558	5.333	499	3.961
Gravel	100	425	2.289	394	1.345
	Oven	546	4.675	483	3.921

### 3 Results and Discussion

#### 3.1. Shrinkage development

The shrinkage–time response, developed over a period of 100 days under standard environmental condition, is shown in Figure 3, for the 40 MPa and 60 MPa concrete mixes. Only results of prisms and cylinders presented. The shape of the shrinkage curves in general agreement with those reported by other investigators (Siddik, et.al. 2009, pp 330-333). The shrinkage results demonstrate that specimen size and grade cause a difference in both rate and shrinkage value. Results show that the magnitude of shrinkage strains is reduced as the section size is increased. Whereas the overall trend of the shrinkage time curves for the concrete mixes shown in figure 2 is similar, there more rapid increase in shrinkage during the early days followed by more steady increase in shrinkage beyond 20-30 days. This effect is more apparent in the case of the smaller test specimens, indicating that the early autogenous shrinkage could take place. Both limestone and gravel aggregate showed an identical development of shrinkage and that probably attributed to their similarity in their elastic and pore structure characteristics (Kenji, 1983, pp 216-

224).

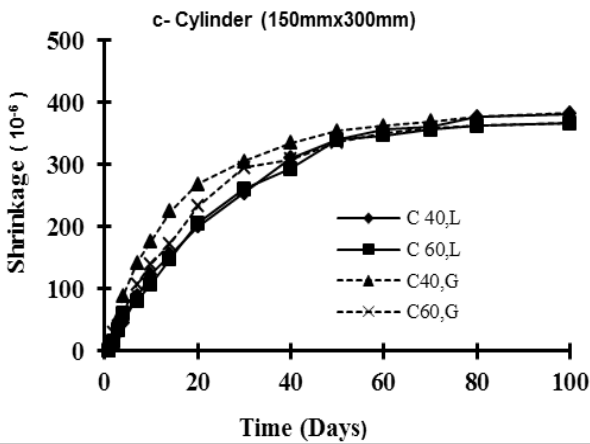
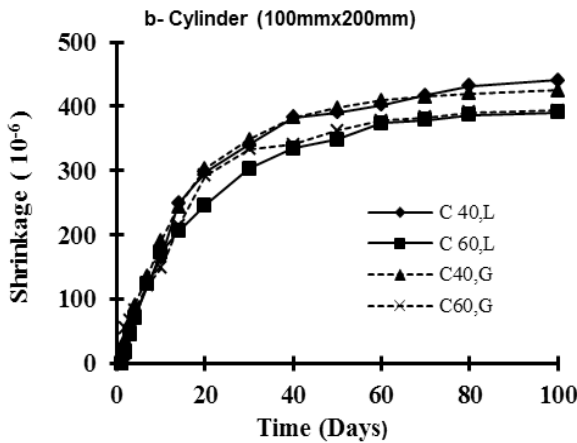
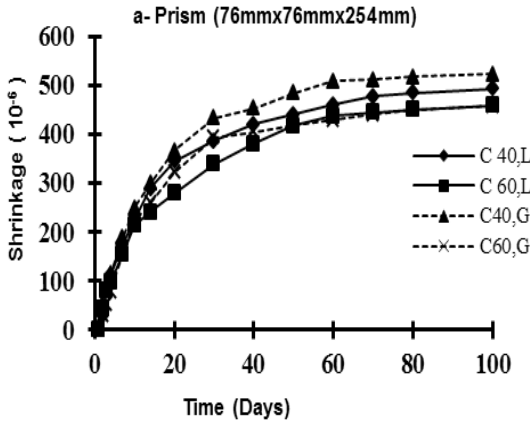
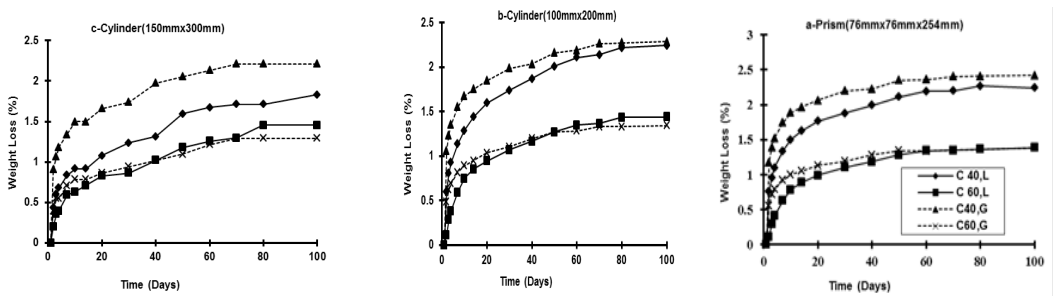


Fig. 2. Development of shrinkage strains with time

## 3.2. Weight loss development

The corresponding weight loss-time responses, during the first 100 days of drying for the 40 and 60 MPa concrete mixes using both types of aggregate are shown in figure 3. The weight loss is expressed as a percentage of the initial weight of the test specimens. Generally, the relationship demonstrated appears to be similar for any given concrete grade and specimen size. It is observed from figure 3 that the weight loss is reduced significantly as the grade is increased and to the lesser extent 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 grade increased is brought by a number of contributions. The main contributing factor is the amount of original water content in each mix. In the case of NSC, a larger amount of adsorbed and evaporated water is available, which tends to increase the drying response. Furthermore, the expulsion of moisture from the gel pores becomes more difficult as the porosity and water content decreased. (Terrill et.al.1986 pp 220-225).



**Fig. 3. Development of weight-loss with time**

## 3.3. Shrinkage and Weight loss relationship

Figure 4, Shows the average shrinkage values plotted against the corresponding average weight loss of prism and cylinder (100x200mm) samples for a period of 100 days. It is found that shrinkage and weight loss has an approximately linear relationship in the period considered and that is in agreement with

other previous published data (Elie, et.al. 1994, pp 300-305). If the weight-loss denoted by (W) in percent and the shrinkage strains in millionth by (S) then, the general linear relationship between both variables could be written as the following:

$$W = a S + b \quad (1)$$

Where: (a) and (b) are constants, sample of their values for the current results with the correlation coefficient ( $r^2$ ) are given in Table 4. From Figure 4 it may be observed that the slope of the linear relationships increasing with specimen size and decreasing with concrete grade. It should be considered that the linear relationships are valid for the time-scale presented in this research. In order to update the current prediction models using shrinkage weight loss data, more research work is needed to extrapolate the relationship beyond this limit (Barr, and El-Baden, 2003, pp 15-25).

Table 4. Sample of regression analysis of Eq.(1)

Regression Constants	(Cylinder (100x200mm			
	MPa 40		MPa 60	
	L	G	L	G
3-ax10	4	3.6	3.4	2.5
3-bx10	476	790	102	358
r <sup>2</sup>	0.94	0.83	0.98	0.89

### 3.4. Shrinkage - weight loss development after oven drying

The ultimate shrinkage and weight loss results after 100 days of standard air drying and subsequent oven drying are shown in Figures 5 and 6 respectively. It was observed that the ultimate weight loss after oven drying represents a considerable amount compared to that in air drying, while the corresponding shrinkage is not following the same amount (Pihlajavaara, 1974, PP 761-771). For example the air drying shrinkage represents a range

from 65% to 93 % of the oven drying, and the ultimate weight loss in air represents about 29% to 53 % of the oven values for all specimen-sizes considered. Ultimate values of both shrinkage and weight-loss shows that shrinkage weight loss relation probably pass through a point of inflection beyond the time-scale considered in which the linearity may vanished or the slope of the relationships changed, which is in turn confirmed with other investigations (Pihlajavaara, 1974, PP 761-771). The observations also confirmed that the shrinkage process occurred due to water loss from a range of pore sizes in the cement paste rather than from one particular size. The overlap of some results give an indication of the similarity in behaviour of the two types of aggregate considered in this research. Through this time scale also, it was observed the independence of ultimate shrinkage on specimen size as reported by some other researches

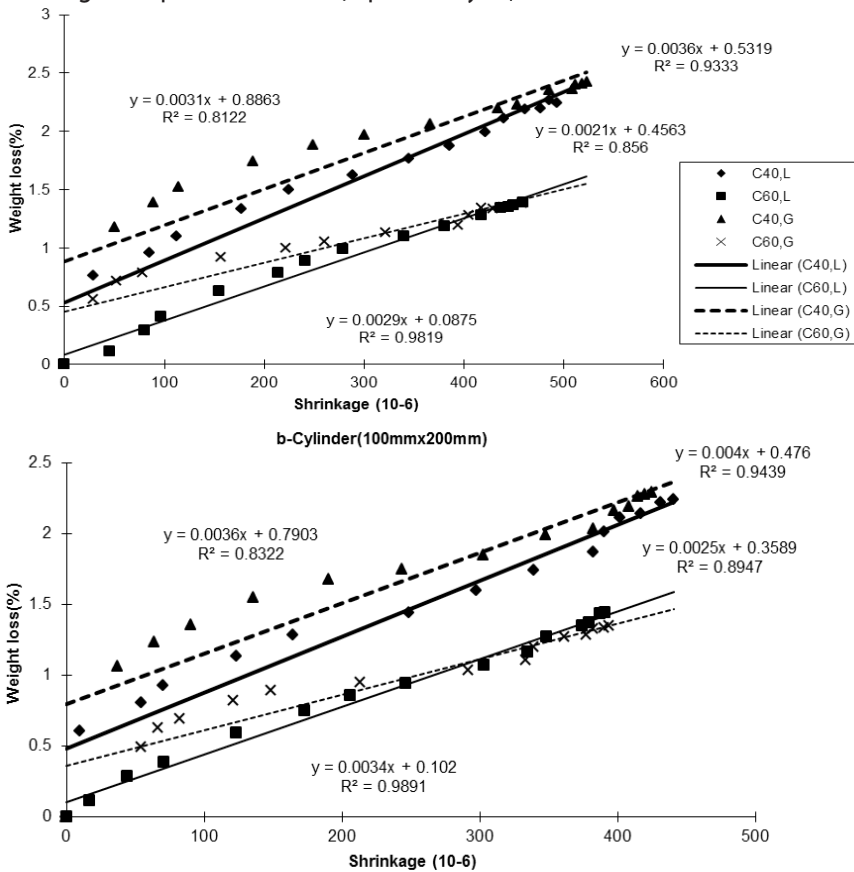


Fig. 4. Sample of shrinkage - weight-loss relationship

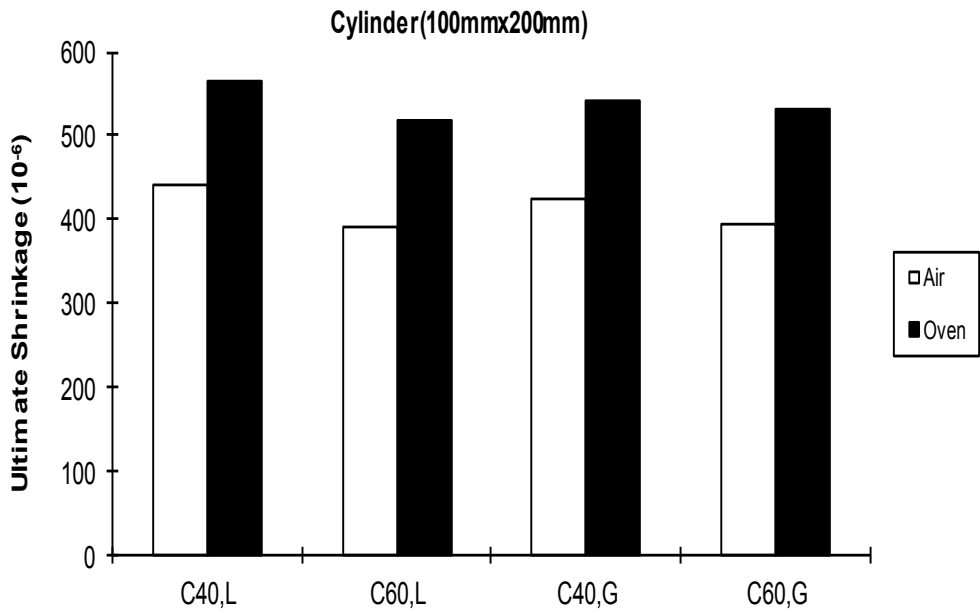


Fig. 5. Ultimate shrinkage values after air and oven drying

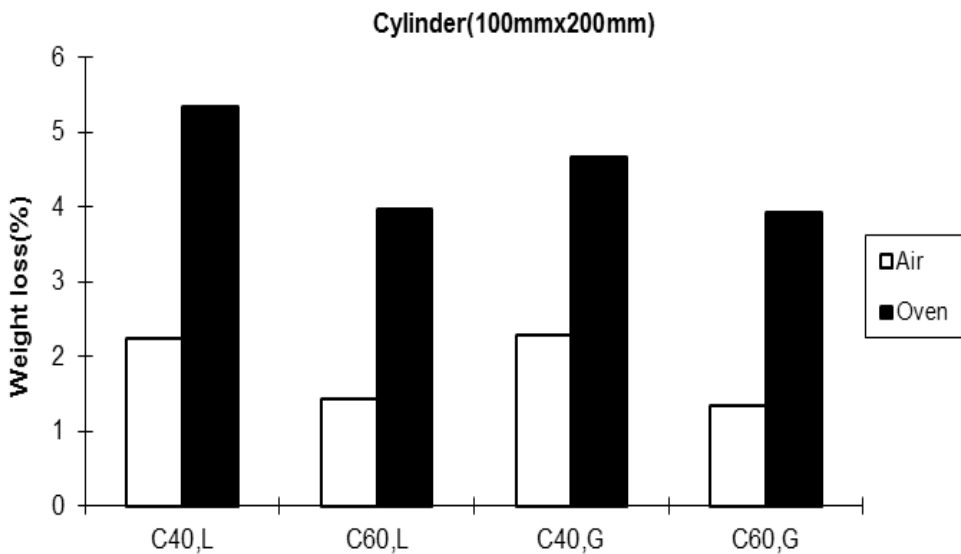


Fig. 6. Ultimate weight-loss values after air and oven drying

## 4 CONCLUSIONS

From the results the following points are the main ones:

1. In all drying period shrinkage and weight loss decreased markedly both in quantity and rate as the specimen size increased and water/cement ratio decreased.
2. The oven drying shows that shrinkage weight loss relation can be considered linear for the short period considered, while for the long term it may have some change in slope.
3. Results showed that both the ultimate shrinkage and weight loss had nonsignificant correlation with sample size.
4. Both limestone and gravel aggregates had showed similar behaviour.

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