Effect of Improper Curing on the Properties of Normal Strength Concrete

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Abstract—**In real applications, 28 days are regarded as proper curing time for concrete. There is a self-evident need to minimize the duration of curing days. For this purpose, this research investigates 1 to 7 days of curing and compares it with concrete cured for 28 days. Three grades of normal concrete strength grade 30, grade 35 and grade 40 were made. After curing, two exposure conditions were applied to the concrete, inside laboratory-controlled environment and outside environment. Results indicate that slump increases with cement content in DOE method at constant water content. The concrete density in all grades reduces when the concrete is subject to inside exposure in comparison with outside exposure. Water loss from concrete reduces with increase in curing days in all concrete grades. Compression strength of all concrete grades increases with increase in curing days. For the uniformity of concrete, ultrasonic pulse velocity indicated that with an increase in curing days, concrete becomes denser and a bit void. Results showed that an increase in curing days also improves the surface quality of concrete. The significance point noticed is that there was not much difference in the concrete properties between 7 days of curing and 28 days of curing in all grades.**

Keywords-curing; water loss; strength; concrete; grades

I. INTRODUCTION

Concrete is one of the major constituents in the construction field. Curing of concrete is an important factor in getting required properties such as strength and durability. Curing is of major importance, especially in the early stages of concrete to enhance the process of hydration of cement, control its temperature and moisture movement in and from concrete. The main reason of curing in early ages is to prevent the loss of water from the concrete, so that it can gain strength in its early days [1, 2]. Curing is also important to prevent plastic shrinkage, permeability loss and to improve resistance to abrasion [3]. Concrete hydration starts when water contacts with cement causing chemical reactions and increasing the concrete's temperature [4]. If the concrete is not cured and exposed to dry air it gets almost the 50% of the strength of cured concrete, if it is cured for 3 days it gets the 60-70%, but if it is cured for 7 days it gets 80-90% of fully cured concrete strength [5]. So the canon is that concrete should be covered for at least 7 days [6]. The water loss of concrete occurs mostly from the surfaces exposed to the environment, where environmental humidity is lower than the humidity inside the concrete, which also results to reduced initial water-cement ratio and occurs due to cement hydration [7, 8]. However, at construction sites, concrete structures are usually exposed to dry conditions from an early stage. Drying of concrete starts at the first day until several days after placing [9, 10]. Theoretically, normal concrete consists of water-cement ratio greater than 0.42 and has enough water in the mixture for completion of its hydration process [4, 11]. On the other hand, in real life practice, in countries where temperature is high and relative humidity is low, concrete is subject to major water loss from the exposed surfaces [12]. Improper curing of concrete occurs almost everywhere but especially it occurs on vertical members, inclined members, areas where water is in low quantity or not accessible for continuous curing [13-15] and where curing cannot be properly supervised [10].

In high-performance concrete, curing is very necessary because of its low water-cement ratio. The cement may reach a final degree of hydration that is less than 50%. Initially, internal relative humidity drops very quickly, if it is not cured and relative humidity is dropped then it stops the hydration process [16]. It can exhibit early age cracking due to volumetric changes through self-desiccation [17, 18]. It happens when water evaporates which results in tensile stress inside the concrete and sometimes tensile stress exceeds the tensile strength [7, 19, 20]. In addition, high-performance concrete mostly contains supplementary cementitious materials, which may require prolonged curing [21]. Due to improper curing in high-performance concrete, cementitious materials hydrate under sealed conditions, empty porosities are created within the concrete because the hydration products occupy less volume than the reacting materials. The core purpose of this research is to investigate the effect of improper curing on water loss, strength, and uniformity. Also, to find the minimum curing days that are enough for concrete to get its desired strength.

II. METHODOLOGY

The range of normal strength concrete is between 30MPa to 40MPa. In this research, three grades of normal concrete were made that are grade 30, grade 35 and grade 40. The design of concrete was made according to DOE method and the content of mixtures is shown in Table I. The slump was kept between 60mm and 180mm. Portland cement was the basic ingredient and Type I cement was used. The maximum size of fine and coarse aggregates was kept to 4.75mm and 10mm respectively.

TABLE I. CONCRETE PARAMETERS

Grade	Mix Design				
	w/c ratio	Cement (Kg/m^3)	Water (Kg/m^3)	Fine Aggregates (Kg/m^3)	Coarse Aggregates (Kg/m^3)
G30	0.55	445	250	875	815
G35	0.51	495	250	840	810
G40	0.47	535	250	805	805

For the evolution of improper curing, a cube of 100mm×100mm×100mm size was casted according to BS 1881-108:1983. Then, samples from each grade mixture of normal strength concrete were cured. After curing, the samples were taken out from the curing tank and kept inside the laboratory (controlled environment) and outside the laboratory (not controlled environment). This process was done for 1 to 7 and 28 days of curing. The workability of concrete mixtures was measured by slump cone test according to BS 1881-102:1983. The density of hardened concrete was measured according to BS 1881-114:1983. Water loss measured by weighing the sample every day until water loss became constant [14, 22, 23]. The compression strength and modes of failure on cubes were tested according to BS 1881-116:1983. Ultrasonic pulse velocity of cubes was carried out according to BS 1881-203:1986. Rebound hammer was tested on cubes according to BS 1881-202:1986.

III. RESULTS AND DISCUSSION

A. Workability

Workability was measured to check the ease of concrete mixture. In this research, the slump was designed between 60mm and 180mm. It was observed that the increase of cement content at constant water-cement ratio increases the workability of concrete because of the total aggregate content decrease in DOE method. Increasing the amount of cement in the mixes and decreasing aggregate content led to an excess of water in the medium and hence, to an increase of the workability as shown in Figure 1. The results agree with the findings in [24].

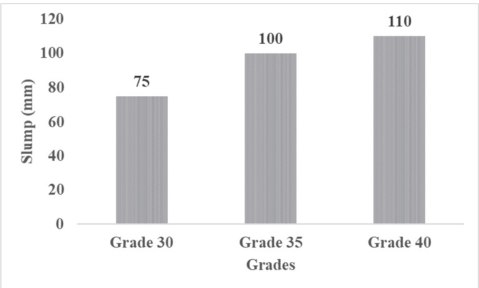

Fig. 1. Slump values of variou concrete grades.

B. Density of Hardened Concrete

Concrete is composed of cement, fine aggregates, coarse aggregates and water. The density of concrete varies depending on the amount and density of aggregates, amount of entrained air, cement and water. Proper curing has a significant effect on the density of concrete [25]. In this research, for grade 30, 35 and 40, the density of concrete behaves differently when samples are exposed to laboratory and outside the laboratory conditions. In all grades, the density of the inside laboratory samples reduced at 28 days compared to the 1st day as shown in Figures 2-4, due to water evaporation from concrete. In the case of samples placed outside the laboratory, the density of concrete increased at 28 days compared to the 1st day as shown in Figures 2-4, mainly due to rainfall. Results agree with the findings in [1, 26]. Another trend was also noticed: increase in days of curing, reduces the difference between the 1-day density and 28-day density of concrete. Seven days of curing have the same density as one day of curing. The concrete density is inversely proportional to the porosity of pore structures in concrete [27]. It can be observed that 7 days of curing do not affect the density of concrete.

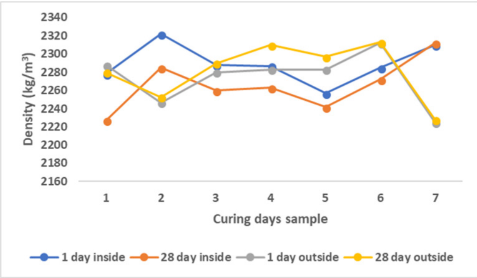

Fig. 2. Density of concrete grade 30 at 1 and 28 days.

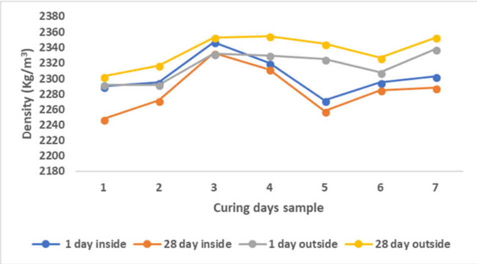

Fig. 3. Density of concrete grade 35 at 1 and 28 days.

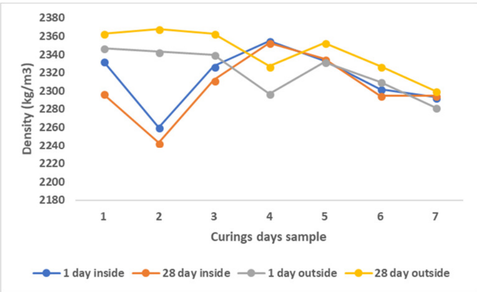

Fig. 4. Density of concrete grade 40 at 1 and 28 days.

C. Water Loss from Normal Strength Concrete

The water content and concrete curing are essential in the concrete early ages. This research is carried out to see the effect of improper curing on the trend of water loss of concrete. For this purpose, the cured samples were kept inside and outside the laboratory for 1 to 7 days. As shown in Figure 5, with increase in the curing days of concrete, water loss becomes low in all grades of normal strength concrete. At 7th day the samples cured for 1 day have more water loss as compared with the samples cured for 6 days. The same trend of water loss for grade 40 and grade 60 resulted in [14, 22]. The samples kept outside the laboratory after each curing day did not show a uniform trend of water loss as shown in Figure 6. It is also noticed that as the water-cement ratio of concrete reduces, it also reduces the water loss due to the relative increase in the cement content, as was also reported in [23, 26].

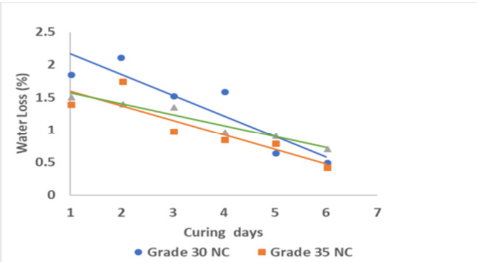

Fig. 5. Water loss from concrete grade 30, 35 and 40 (inside).

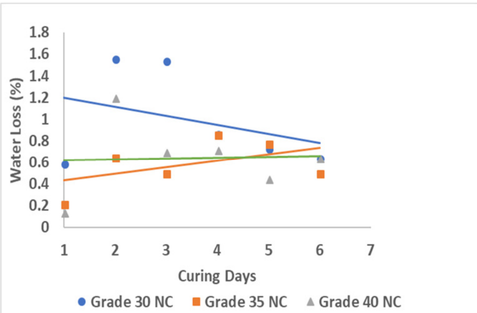

Fig. 6. Water loss from concrete grade 30, 35 and 40 (outside).

D. Ultrasonic Pulse Velocity

The ultrasonic pulse velocity (UPV) test is a non-destructive test that measures quality and homogeneity of concrete specimens to determine the existence of pores and cracks [28]. Experimental results indicate that, in all grades of concrete, increase in curing duration results in increased UPV due to more concrete hydration, it reduces voids and makes concrete dense [29]. UPV values are in the range of 3.5-4.5, as shown in Figures 7-9, which comes in good concrete quality, as shown in Table II.

TABLE II. CONCRETE QUALITY BASED ON UPV [29]

UPV (Km/s)	Quality of Concrete
>4	Excellent
3.5–4.5	Good
3.0–3.5	Doubtful
2.5–3.0	Poor
<2.5	Very Poor

It is also noticed that 28 days curing have the highest UPV and this concrete comes in the category of excellent quality. Less UPV indicates high porosity of concrete and vice versa. Higher values of UPV give higher concrete strength [30, 31].

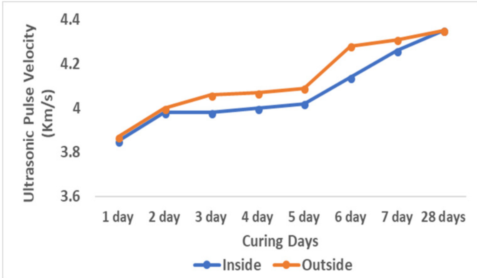

Fig. 7. Grade 30 UPV results at 28 days.

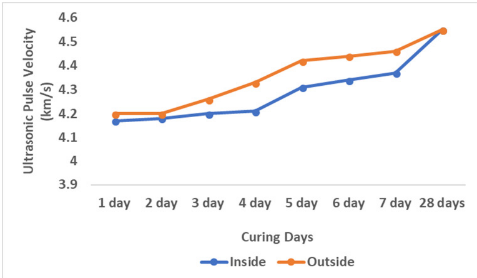

Fig. 8. Grade 35 UPV results at 28 days.

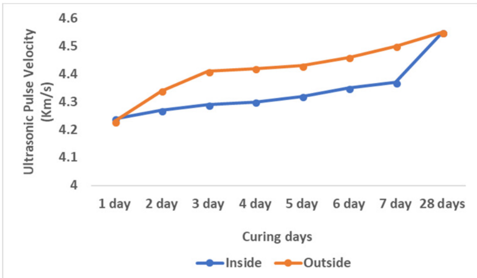

Fig. 9. Grade 40 UPV results at 28 days.

E. Rebound Hammer

Rebound hammer test was carried out to investigate the hardness and surface quality of concrete in depth up to 30mm inside from the surface. In this research, the test was carried out because water loss mostly occurs from the surface of concrete. First rebound hammer test should not be carried out before 14 days and later after 3 months as prescribed in BS-1881:202-1981. In this research, it is noticed that increase in days of curing of concrete also increases rebound hammer number in all grades of normal strength concrete as shown in Figures 10-12. Increase in grade of normal strength concrete also increases rebound hammer number. Rebound hammer number of 1 day curing at 28 days is less than the one after 7 days and 28 days of curing because hydration process got stopped due to less curing than required and surface did not become hard. It has also been observed that 7 days curing, and 28 days curing have not much difference in rebound hammer number at 28 days in all grades of normal strength concrete. The comparative rebound hammer values according to British standard are given in Table III. So, 1 day to 7 days curing at 28 days was lying in good concrete quality, but 28 days curing has an excellent concrete quality in all grades of normal strength concrete. The same trend of results is also shown in [32].

TABLE III. COMPARATIVE REBOUND HARDNESS VALUES

Rebound Number	Quality of Concrete
>40	Very Good
30-40	Good
20-30	Fair
<20	Poor
0	Very Poor

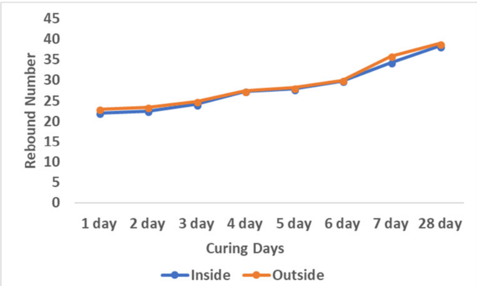

Fig. 10. Rebound number of grade 30 at 28 days.

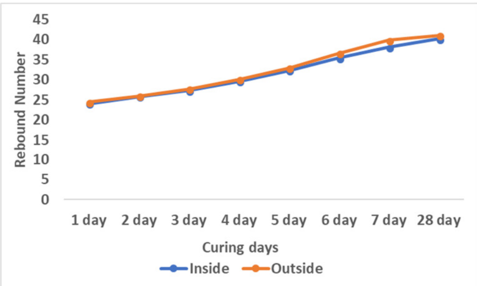

Fig. 11. Rebound number of grade 35 at 28 days.

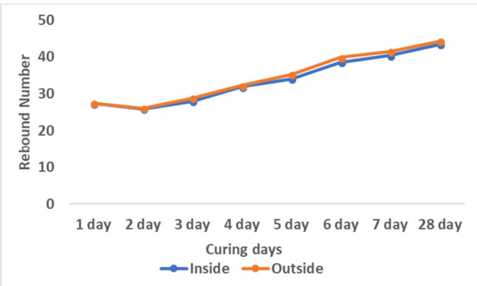

Fig. 12. Rebound number of grade 40 at 28 days.

F. Compression Strength

Curing is a very important factor for the concrete to gain compression strength and is essential when there is high chance of water loss. That is occurring at the early ages of concrete, when cement hydration takes place. In this research, all samples were compared with the 28-day curing samples of concrete. As shown in Figure 13, with increase in curing days the strength of concrete in all grades of normal strength concrete also increases, when exposed inside and outside the laboratory. If the grade 30 concrete is cured for 1 day and then kept 27 days inside the laboratory, then its compression strength at 28 days is 38% less than 28 days curing strength and 25% less than 7 days curing strength. When the sample was kept outside, its 1 day curing strength at 28 days was 26.5% less than 28 days curing strength and 20.5% less than 7 days curing strength. The same trend is also seen in other grades of concrete. The results in [14, 22] also showed that 1 day curing at 28 days has less strength when compared with 28 days curing strength, almost the same percentage of loss is noticed. In Figure 13, it is also noticed that the samples kept outside the laboratory have a little bit higher strength when compared with the samples kept inside the laboratory. This occured because of the additional water gained from rain. From Figure 13, it is also noticed that there is not much difference in the strength of 7 days curing and 28 days curing, inside samples cured for 7 days have 10% less strength than 28 days curing strength at 28 days and outside samples had 5% less strength at 28 days.

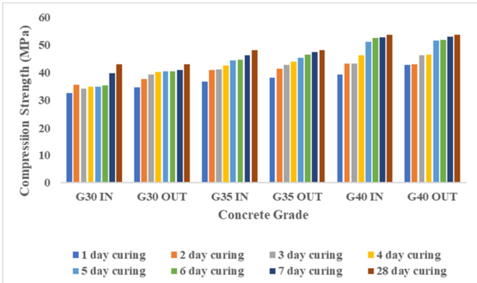

Fig. 13. Compression strength values of grade 30, 35 and 40 at 28 days.

IV. CONCLUSION

This research concludes that slump of concrete increases in DOE method, when cement increases at constant water content and total aggregate content reduces for all grades of normal strength concrete. The density of concrete at 28 days is reduced when subjected to exposure inside the laboratory after curing. The water loss from concrete decreases with increasing curing days and all kept inside grade samples behaved differently than the samples subjected to outside exposure because, due to rainfall water, water loss was not estimated properly. The compression strength increases with increase in curing days in all grades of normal strength concrete but outside exposure samples had slightly higher compression strength when compared to the samples subjected to inside exposure. The uniformity of concrete also improved with increase in curing days, which indicates that by increasing the days, concrete becomes dense and voids lessen. Rebound hammer test results indicate the concrete surface quality. The rebound hammer value increases with increase in curing days. The core point to be noticed is that there was no significant difference in the properties of 7 days curing and 28 days curing of all grades of normal strength concrete at 28 days, so it can be concluded that 7 days curing is enough for normal strength concrete.

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