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COMPARISON OF DIFFERENT CURING EFFECTS ON CONCRETE STRENGTH

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ABSTRACT
The purpose of this investigation was to conduct a laboratory test program on how much different curing conditions affect the attainable strength of concrete. To achieve this purpose, a laboratory test program was conducted. The laboratory program consisted of casting 150 mm by 150 mm concrete cubes using eight different mix designs and subjecting them to six different curing conditions. In order to investigate the influence of curing conditions, on the compressive strength of concrete cubes, for each mix design three cubes were chosen for every curing regime. The curing regimes employed were: immersion in drinking water; covering with wet hessian and polythene sheet; keeping under dry laboratory conditions; keeping in open air; curing compound and steam curing. Except for steam curing system, the specimens of which were tested at the age of three days, for all other curing conditions, the compression tests were performed at the age of 28 days. It has been found that the curing system greatly influences the concrete strength. While the highest gain in compressive strength was recorded for cubes covered with wet Hessian and polythene sheet, the lowest gain in compressive strength was recorded for the specimens cure using steam curing.

Keywords: concrete, compressive strength, curing systems

1. INTRODUCTION
Concrete is a mix of cementitious (binding) solids [e.g., cement (calcium silicates, calcium aluminates, and calcium alumino-ferrites) and sometimes fly ash (aluminates and silica) and micro-silica], aggregate (sand and stones), and water. The cementitious solids of concrete, upon mixing with water, react in highly exothermic, temperature-dependent hydration reactions (the higher the temperature, the faster the hydration reactions) producing a firm, hard mass. There are four major stages in the hydration reactions: 1) surface reactions produce a ‘‘gel’’ on cementitious particles and release heat, lasting about 30 min, 2) hydration is slowed for several hours because diffusion of water into the cement particle is inhibited by the gel, 3) vigorous hydration and heat development occur for up to 20 h as water reaches un-hydrated cement inside the gel coating (stiffening of the concrete occurs during this stage), and 4) hydration continues to decline for years [1-3].

To ensure that hydration continues, especially at the surface, the concrete must be cured. Curing means water at the surface of the concrete is retained to allow the concrete to hydrate to a point where it has a strong, durable structure. If curing is inadequate, the water evaporates and hydration stops, resulting in a low-strength concrete. If adequate moisture isn't maintained in the curing environment, the concrete won't develop maximum compressive strength, and cracking may occur. Durability of the concrete may also be reduced due to inadequate hydration of the cementitious material.

Ambient atmospheric conditions can adversely influence the thermal and moisture structure of freshly poured concrete. If concrete becomes too warm or temperature gradients too large during the first several days after the concrete is poured or if there is insufficient water in the concrete, the concrete may crack or may not develop its maximum potential strength, reducing its long-term durability [4-7] .Surface drying may even affect the underlying concrete, as water will be drawn from the lower levels into the dry surface concrete. Any significant internal drying also will slow or stop hydration and the structure may not gain adequate strength.

For hydration to continue, the relative humidity inside the concrete has to be maintained at a minimum of 80%. If the relative humidity of the ambient air is that high, there will be little movement of water between the concrete and the ambient air and no active curing is needed to ensure continuation of hydration. Prevention of the loss of water from the concrete is of importance not only because the loss adversely affects the development of strength, but also because it leads to plastic shrinkage, increased permeability and reduced resistance to abrasion.

Continuous curing for a specified time, starting as soon as the surface of the concrete is no longer liable to damage is desirable. Such conditions can be achieved by continuous spraying or pounding or by covering the concrete with wet burlap. Probably the best method for curing concrete, although sometimes the least practical, is to flood the surface continuously with water for the first week after placement. But, if concrete dries between soakings, this alternate wetting and drying may actually damage the concrete. When water curing, the sprinkler should be going continuously for at least one week. On inclined or vertical surfaces, soaking hoses can be used. If w/c is low, continuous wet curing is highly desirable.

Another method of curing is called water barrier method. The techniques used include covering the surface of the concrete with overlapping polyethylene sheeting. White sheeting is preferable because it has the advantage of reflecting of solar radiation in hot weather [8].

Method of spraying curing compounds, which form a membrane may be used as well. It is obvious that the membrane must be continuous and undamaged. The timing of curing is also critical. The curing spray should be applied after bleeding has stopped. The most common way to cure new concrete is through a liquid membrane-forming curing compound also known as "cure and seal". These materials are usually sprayed or rolled on the surface. When dry, they form a thin film, which restricts moisture evaporation from the surface.

Timing is most important when using a curing compound. These products must be applied as soon as final finishing is complete. Otherwise, they could mar the concrete's surface. Also, the ready mix concrete supplier should be checked for recommendations on what to do when cold/freezing temperatures are anticipated. The next most important thing is the application rate. In this regard the manufacturer's recommendations should be followed completely.

The optimum time is the instant when the free water on the surface of the concrete has disappeared so that water shine is no longer visible [9].

Most penetrating sealers are made from derivatives of silicone called silanes or siloxanes designed to penetrate concrete pores. Once there, they react with the alkaline materials and moisture present to form silicone, making concrete water-repellent. While penetrating sealers usually cost more, they should last longer. Another reason for penetrating sealers popularity is that, when properly applied, they don't change the concrete's appearance. The major concern is that there can be no other membrane cure or sealer on the concrete when applying and the concrete must be at least 28 days old.

Internal concrete temperature is the most important factor affecting early compressive strength of concrete. Because of this, external heat is usually applied to produce high early compressive strengths concrete products after 12 to 18 hours of curing. Temperature is critical to meeting the dual concerns of higher early strength or reduced curing time. These methods are called accelerated curing methods. High early concrete strengths are most efficiently produced by increasing the internal temperature of the concrete while maintaining high moisture content in the curing environment. Heating reduces the relative humidity of the air surrounding the concrete. Thus, moisture must be added to the heated air to maintain the same relative humidity of the air.

Three heating methods are commonly used to accelerate curing: 1) Discharging steam or hot air directly into the curing environment puts the heating medium directly in contact with the concrete. 2) Enclosing steam or hot water in pipes heats the concrete by convection and radiation. 3) Attaching electrical resistance wires to the forms and covering them with insulation heats the product by heating the forms.

Circulating steam around the products is one of the most widely used accelerated curing methods, primarily due to the ease of producing and transporting steam to the concrete member. It’s an efficient method that increases the temperature and maintains a 100% relative humidity around the concrete products. Steam can be produced in high or low-pressure boilers, then piped to the casting bed, or generated by smaller steam packs located close to the products. An advantage of steam is that it contains relatively large quantities of heat per pound of steam at a relatively low temperature. This provides both an effective and economical method of transferring heat from the boilers to the concrete products. Heating air and discharging it directly into the curing environment can also increase internal temperature. There are two problems with this type of system. First, exhaust gases of unvented fossil fuel heaters contain carbon dioxide that combines with calcium hydroxide, a byproduct of cement hydration, forming weak calcium carbonates instead of strong calcium silicate hydrates. This produces a white powder on the concrete’s surface. Second, reduced moisture in the air allows surface drying of the concrete. If heated air is used to accelerate curing, the products should be covered to prevent moisture loss or misted with water to increase the relative humidity of the surrounding air and prevent premature drying.

The accelerated curing cycle can be divided into three periods of preset, rising temperature, and maximum temperature. Little or no cement hydration occurs during preset. Initial set ends the preset period. Heat shouldn't normally be applied until after initial set has occurred. Duration of the preset period is affected by admixture type and dosage, cement type, presence of pozzolans or ground granulated blast furnace slag, initial concrete temperature, and air temperature in the curing environment.

Advantages of proper curing includes: a less permeable, more water-tight concrete; reduced permeability means the concrete will be more resistant to freezing, salt scaling and attack by chemicals; prevents formation of plastic shrinkage cracks caused by rapid surface drying; increases abrasion resistance as the surface concrete will have a higher strength and significant reduction in scaling problems.

Curing should begin immediately after the finishing operation. Minimal delay is especially important in hot and/or dry weather to avoid rapid evaporation from the concrete surface. The benefits of curing concrete are significant, as can be the problems if curing is not performed as detailed above.

In order to investigate the influence of curing conditions, on the compressive strength of concrete cubes, for each mix design, three cubes were chosen for every curing regime. The curing regimes employed were: immersion in drinking water; covering with wet hessian and polythene sheet; keeping under dry laboratory conditions; keeping in open air; curing compound and steam curing. Except for steam curing system, the specimens of which were tested at the age of three days, for all other curing conditions, the compression tests were performed at the age of 28 days.

2. EXPERIMENTATION

2.1. Materials and Specimens

Concrete used in during these experiments, was made from ordinary Portland cement (binder), natural zone 2 sand (fine aggregate), basalt aggregate with maximum size of 20mm (coarse aggregate) mixed with sufficient drinking water and required additives where necessary. The mix proportions of eight different mixes used in this investigation are listed in Table 1.

Table 1: Mix designs.

No.	Cement (Kg/m^3)	Water (Kg/m^3)	Fine aggregate (Kg/m^3)	Coarse aggregate (Kg/m^3)	Super Plasticizer (Kg/m^3)	Silica Fume (Kg/m^3)
1	250	205	1227	661	0	0
2	360	205	1050	730	0	0
3	435	205	962	740	0	0
4	512	205	895	730	0	0
5	603	205	820	715	0	0
6	574	195	651	937	0	0
7	556	130	685	937	7.85	0
8	513	130	685	1080	7.85	43

In order to see the effect of different curing regimes on the compressive strengths of concrete, 150 mm cubes were prepared using mix designs shown in Tables 1. All of the cubes were covered with damp hessian and left to cure in the moulds for 24 hours. They were then removed from the moulds and labeled. Depending on the curing method chosen, the cubes were kept in water tank, covered with wet hessian and polythene sheet, covered with chemical curing agent, left under dry laboratory conditions, left in open air, or moved to accelerated steam curing chamber.
Except for the cubes cured under steam which were tested at the age of three days, the compressive strength of the specimens cured under other curing regimes were measured at the age of 28 days in accordance with BS1881: Part 116 [10].The steam curing systems was performed as specified in ASTM C 267 and 579. The temperature cycle used in this system of curing is shown in Figure 1.

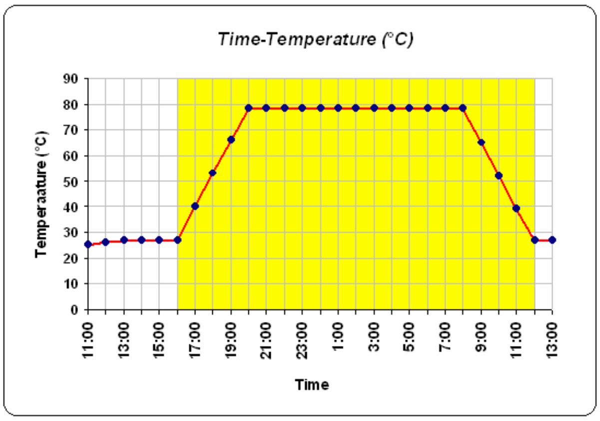

Figure 1. Duration and the temperature employed for the accelerated curing.

3. RESULTS AND DISCUSSION

The results of measured compressive strengths of cubes made using eight different concrete mixes and cured by immersion in water tank are shown in Figure 2.

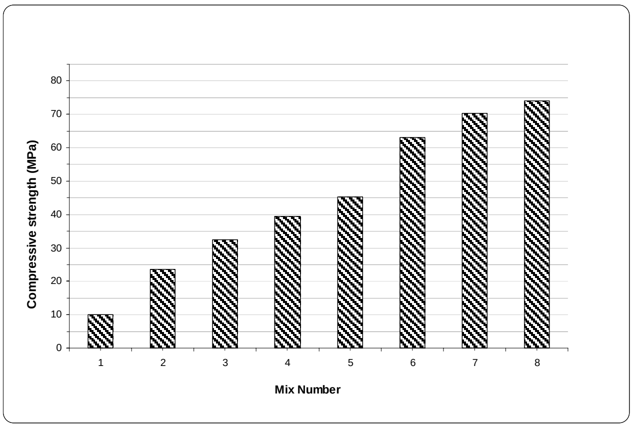

Figure 2. Compressive strengths of eight different mixtures cured by immersion

As it can be seen from this figure, the compressive strengths recorded for eight different concrete mixes range from 10 to about 75 MPa.
As is shown in Figure 3, the compressive strengths of the cubes made out of eight different concrete mixes, cured by wet hessian and polythene sheet coverage, are shown in Figure 3. This figure shows that, under this system of curing the cubes compressive strengths are seen to be between about 12 to 80 MPa. If these values are compared with their relative values recorded for the water immersion curing systems, it can be seen that covering the concrete cubes with wet hessian and polythene sheet tend to increase the cubes compressive strengths. It should be noted that although this increase is not very significant but it reflects the importance of the covering systems and their influence on the strength attained.

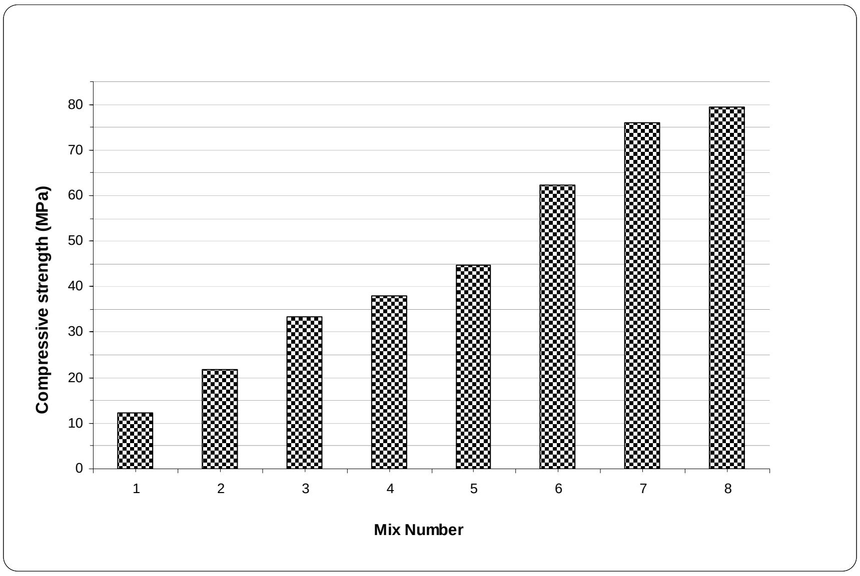

Figure 3. Compressive strengths of eight different mixtures, cured under wet hessian and polythene sheet

The results of the cubes compressive strengths cured using curing compound are shown in Figure 4. It can be seen from this figure that the measured compressive strengths of the cubes cured under this system of curing, has gained strengths from about 10 to about 64 MPa. Comparison of these results with those obtained for the other two curing regimes tends to show that the use of curing compound as curing agent produces lowest compressive strengths among the three curing systems.
Examination of the results shown in figure 5, which belongs to the concrete cubes cured by steam curing, tends to suggest that this curing method has produced the lowest compressive strengths among the four curing regimes discussed so far. Because while the lowest compressive strength recorded for this system appears to be about 6 MPa, the highest value recorded is about 57 MPa.

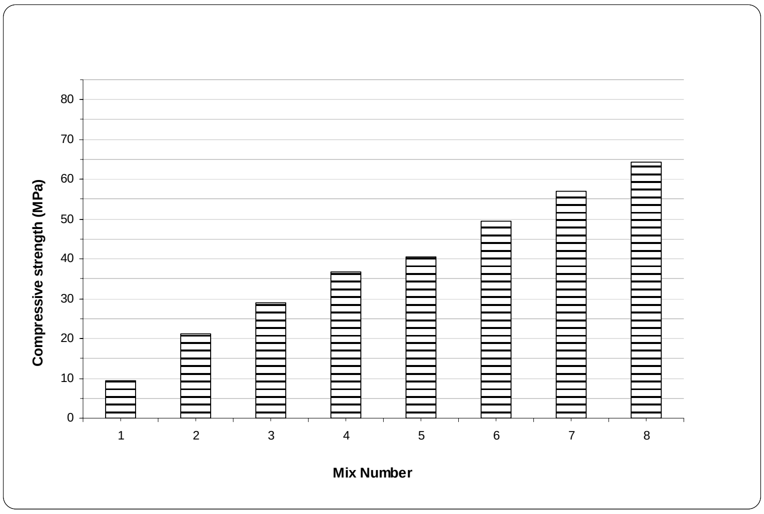

Figure 4. Compressive strengths of eight different concrete mixtures, cured using curing compound.

It should be noted compared with 28 days used for other curing systems, the age of testing used for this system of curing was three days. The results of this series of experiments tends to show that this curing system can be used where early concrete strength is of paramount importance.

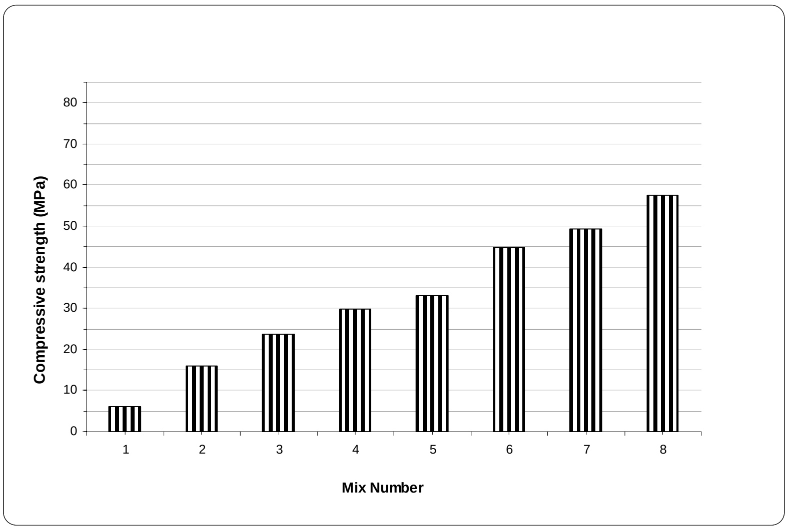

Figure 5. Compressive strengths of eight different concrete mixtures, cured by live steam

The compressive strengths of the cubes left under dry laboratory conditions, are shown in Figure 6. Examination of Figure 6 shows that if the concrete cubes are left under dry laboratory condition, compared with the other curing systems discussed so far, their compressive strengths would tend to decrease. This decrease appears to be more for weaker concrete mixes.

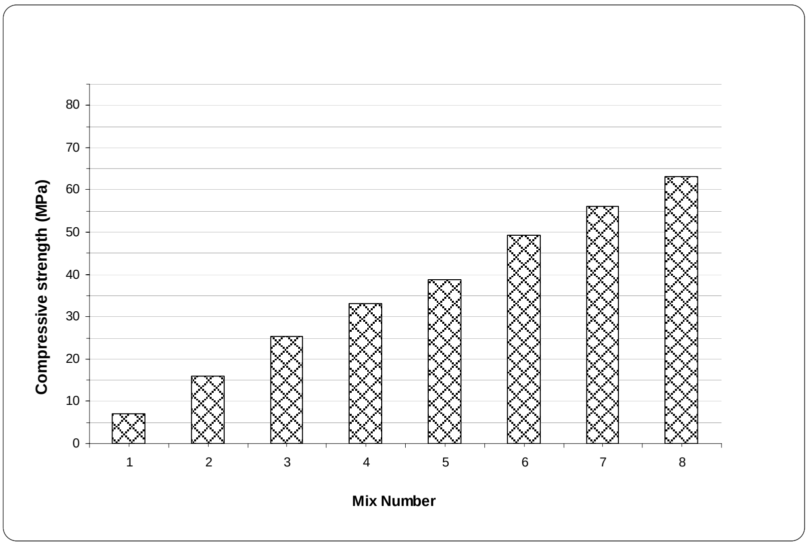

Figure 6. Compressive strengths of different concrete mixtures, left under dry laboratory conditions

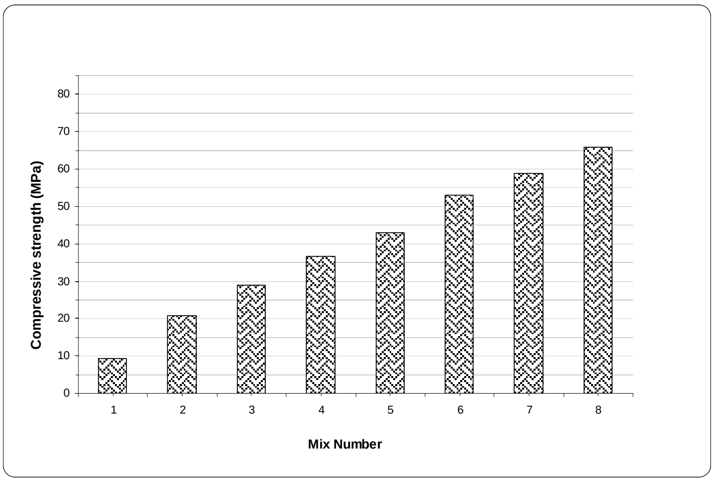

Figure 7. Compressive strengths of eight different concrete mixtures, left in open air

Figure 7 shows the compressive strengths of the cubes kept in open air after their removal from the mold. Examination of these results tends to indicate that compared with normal wet curing, leaving the concrete cubes in open air affects their compressive strengths. The compressive strengths of the cubes kept in open air for 27 days, appears to rage from about 8 MPa, to about 66 MPa. Comparison of these values with the respective values of the cubes kept under dry laboratory

conditions, tends to show an increase for the attainable compressive strengths of the cubes kept in open air. It should be noted that during the conduction of these experiments the temperature of the open air never reached below about 10 degree C. Comparison of the respective results shown in figure 8 tends to suggest that, among the curing systems employed covering of the concrete cubes with wet hessian and polythene sheet appears to have the highest positive effect on the attainable concrete compressive strength. It can also be seen from this figure that, compared with the results obtained from other curing regimes, steam curing tends to produce the lowest cube compressive strengths for the employed mix designs. Figure 8 also shows that compared with wet coverage, the immersion method of curing, tends to produce lower compressive strength.
The collective results of all the cubes cured, using six different curing regimes are depicted in Figure 8.

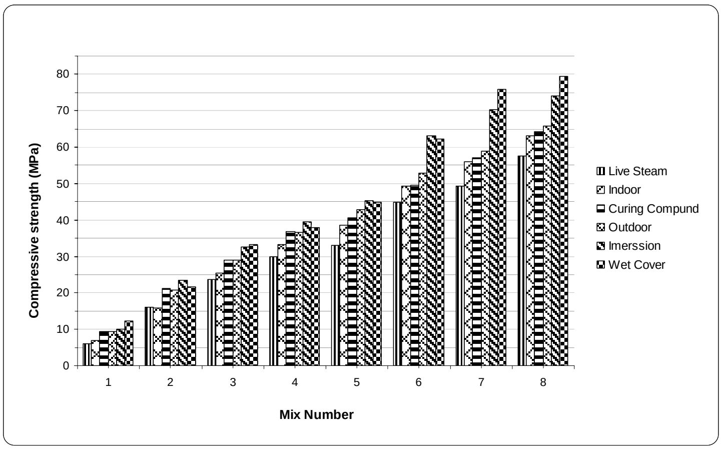

Figure 8. Compressive strengths of eight different concrete mixtures cured under different curing systems

4. CONCLUSIONS

From the results presented and discussed in this paper following conclusions can be made:

1) Different curing systems have different effects on the compressive strength of concrete.
2) Among the curing systems employed in this research, covering with wet hessian and polythene sheet produced the highest concrete compressive strength.
3) In comparison with covering with wet hessian and polythene sheet, the immersion curing system, produced lower compressive strength.
4) Steam curing produced the lowest compressive strength among the curing systems examined.
5) Compared with wet curing systems, leaving the cubes in open air and dry laboratory conditions after 24 hours of casting, tends to produce lower compressive strength.

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