EFFECT OF CURING DELAY ON THE COMPRESSIVE STRENGTH OF CONCRETE

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Abstract: Curing is very vital in the production of strong and durable concrete. This research work investigates the effect of curing delay on the compressive strength of concrete. Mix ratios of 1:1.5:3 and 1:2:4 were prepared with two different water/cement ratios, that is, water/cement ratios of 0.5 and 0.6. A total of 240 cubes were cast, that is, 60 cubes each of 1:1.5:3 with water cement ratio of 0.5 and 0.6, and 1:2:4 with water cement ratio of 0.5 and 0.6. Curing ages of 7, 14, 21, and 28 days were used. However, curing delays of 0, 1, 2, 3, and 4 days were used in this piece of work, where zero curing delay is serving as the control. The work was carried out under very dry environmental condition with relative humidity ranging from 10 – 15%. The results showed that, compressive strength of concrete decrease with the increase in the duration of curing delay, but the effect reduce with the increase in curing period. However, the curing delays result to irreversible loss of compressive strength of the concrete. The richer mixes have more resistance to loss of strength compared to lean mixes. The lower the water/cement ratio, the higher the resistance to loss in compressive strength caused by curing delay. It is therefore, recommended that concrete should be properly cured without delay to avoid loss of strength.

Keywords: Curing Delay, Compressive Strength, Water/Cement Ratio, Mix Ratio

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INTRODUCTION

Curing is the process of preventing the loss of moisture and maintaining temperature on the concrete at early stages of hardening (Newman & Choo, 2003; Al-Ani & Al-Zaiwary, 1988). The mixture of concrete which comprises of aggregates (fine and coarse), cement, and water, and in some cases, admixtures, uses the moisture (water) in the mix for the hydration of cement. Some of the water in the mix dries out as a result of evaporation (Safiuddin, Raman, & Zain, 2007) and the other part is consumed by the hydration reaction of the cement. So, for the full hydration reaction to occur, water should be added to the set concrete so as to supplement the water that was lost due to evaporation.Ye, Zollinger, Choi, & Won, (2006) reported that, strength of concrete increases with decrease in void ratio, consequently the permeability of the concrete reduces. The voids in concrete, apart from entrained and entrapped air, are formed as the volume originally occupied by water has been exhausted, as the water is used up during the hydration process. Voids which were initially filled with water in the concrete are occupied by hydration products as hydration continues. In as much as these pore spaces are adequately filled with hydration products, the quality of concrete will be satisfactory. They however pointed out that, for concrete with less capillary voids to be produced, two things should be born in mind. One is decreasing the quantity of water in the fresh concrete; that is why Aluko, (2005) asserted that concrete with low water/cement (w/c) ratio gives concrete of better quality. The other one is to encourage the hydration of cement as much as possible so that the hydration products will fill the voids. Based on this reason, not all mixtures need to reach their full hydration potential to achieve acceptable quality, particularly when low w/c ratio is used. However, for the hydration to continue the concrete must be saturated or nearly saturated with water; this enables the pores in the concrete to be filled with water. The water-filled pores will eventually be filled with the hydration products. The temperature and the duration of curing (being in humid environment)are the main environmental factors that play important roles in proper curing, that is, in influencing some of the properties of concrete (Mannan, Basri, Zain, & Islam, 2002; Aminur, Harunur, Teo, & Abu Zakir, 2010).Despite the fact that the rate of hydration reaction as well as evaporation increases with increase in temperature, the ultimate strength achieved by the concrete cured with hot water is usually lower than that cured with cold water (Newman & Choo, 2003), even though higher temperature leads to rapid gain in strength. However, extreme temperatures have negative effect on the on the strength development of the concrete.The hydration of cement that is cured with cold water forms more stable and durable chemical products, which gives the concrete its strength that would not loss subsequently (Shetty M. S., 2005).Appropriate curing is essential for concrete to attain designed strength and maximum durability, particularly for concrete exposed to extreme environmental conditions at an early age (Cable, Wang, & Zhi., 2002). It was reported that relative humidity of 80% and above is required for the continuous hydration of the cement during curing processes of concrete(Neville, 1997; Safiuddin, Raman, & Zain, 2007).The evaporation reduces the amount of available moisture in the concrete which causes reduction in relative humidity, and thereby retards the hydration of cement(Safiuddin, Raman, & Zain, 2007).For concrete to attain its prospective strength and durability, it must be cured for a reasonable period of time (Krishna, Kumar, & Khan, 2010). Anhydrous calcium silicate and aluminate in Portland cement react with water to form hydrated products. These hydrated products occupy more space compared to the anhydrous particles; as a result, bind aggregates together(Aminur, Harunur, Teo, & Abu Zakir, 2010). The bonding is a function of water-cement ratio of the initial mix and curing period. When water for hydration of the concrete at the early age is not sufficient to give a relative humidity of 80% and above, the hydration will not continue and the resulting concrete may not possess the required properties such as strength and durability. It is essential to keep enough moisture in the concrete while the cement is actively hydrating, particularly at early ages (Ye, Zollinger, Choi, & Won, 2006), because if concrete is improperly cured for a long period of time, it might not regain the strength of continuously cured concrete even when subsequently cured for long period (Carrier, 1978;Zain, Safiuddin, & Yusof, 2000; Ramezanianpour &Malhotra, 1995). The products of hydration that predominantly give strength, increase resistance to chemical attacks, and increase durability of the concrete, are obtained from the reaction of C_3S and C_2S and water to produce C – S – H. Mamlouk & Zaniewski, (2006) asserted that, if concrete is left without curing after casting and allowed to be air dried, it will only gain 50% of the strength of the one that is properly cured. However, they equally reported that, concrete cured for three days gains 60% of its targeted strength, after seven days, it would achieve 80% of the strength. Furthermore, the hydration reaction stops when curing is suspended for some time and reactivates when the curing resumes and the relative humidity within the concrete reaches 80%. Ye, Zollinger, Choi, & Won, (2006) argued that only certain depth of the concrete from the surface that was termed as "curing affected zone (CAZ)" which ranged between ¼ and ¾ of an inch, would be influenced by curing. While the inner section of the concrete would have sufficient moisture for hydration of the cement to continue. They reported that properties of the concrete such as strength and modulus of elasticity might not be sensitive to curing effectiveness. They hoewever inferred that properties that have to do with surface of the concrete such as surface hardness, abrasion resistance, scaling resistance, surface permeability and absorption, surface cracking and other surface-type properties might be strongly affected by curing effectiveness. It was equally reviewed that the depth of the surface zone which is directly affected by curing can be up to 20 mm in temperate climatic conditions, and up to 50 mm in more extreme arid conditions.

Properties of the concrete outside this zone may not be affected considerably by normal curing (CIRIA, 1997). Newman & Choo, (2003) reported that delay in curing between finishing the concrete surface or removal of formwork and start of the curing, and erratic curing within the first two or three days can impede the effectiveness of the curing. These conditions may lead to partial blockage of the surface capillaries of the concrete by the calcium hydroxide at the surface being converted to calcium carbonate as a result of evaporation of pore water in the concrete. The resultant calcium carbonate that partially blocks the capillaries makes it difficult to get water back into the concrete. Aminur, Harunur, Teo, & Abu Zakir, (2010)found out that delay in curing at the early age of casting reduces the compressive strength of the concrete, even though, it recovers the loss of strength at the later days. Conversely, Al-Ani & Al-Zaiwary, (1988) reported that the strength loss was irrecoverable, even though, the strength increased when the curing was reintroduced. This piece of work investigates the effect of curing delays on the compressive strength of concrete.

MATERIALS AND METHODS

Materials

The materials used in the production of concrete cubes were Dangote ordinary Portland cement (grade 43), 19 mm crushed granites and the river sand obtained from Shamka near Damaturu, the state capital of Yobe in Nigeria. The water used was the ordinary tap water. The experiment was carried out in February through March of 2017, the period was so chosen because of the dry atmospheric air of such period in the area. The constituents of the concrete, that is, cement, fine and coarse aggregates, and water were tested for the specific gravity, and bulk density according to BS 812-2 (1995). However, the sand used was subjected to sieve analysis (Figure 1) and silt content tests and the aggregate crushing value was conducted on the coarse aggregates in accordance with BS EN 1097-2 (2010).

Table 1: Physical Properties of Materials

Properties	Fine Aggregates	Coarse Aggregates	Cement	Water
Specific Gravity	2.67	2.82	3.16	1.00
Silt content (%)	7.3%	-	-	
Fineness Modulus	2.89	6.54	-	
Aggregate Crushing value (%)	-	28		
Unit weight (kg/m^3)	1503	1679	1491	1000

Mix ratios of 1:1.5:3 and 1:2:4 were prepared with two different water/cement ratios, that is, water/cement ratios of 0.5 and 0.6. A total of 240 cubes were cast, that is, 60 cubes each of 1:1.5:3 with water cement ratio of 0.5 and 0.6, and 1:2:4 with water cement ratio of 0.5 and 0.6. Curing ages of 7, 14, 21, and 28 days were used. However, curing delays of 0, 1, 2, 3, and 4 days were used in this piece of work, where zero curing delay is serving as the control. Slump test was carried out for the fresh concrete. The cubes that were subjected to curing delays were left without curing after removal of the moulds with the surounding humidity of 10 – 15% throughout the period of curing delay. The relative humidity of the environment was measured using psychrometer which consists of dry-bulb and wet-bulb thermometers. The cubes were then cured by immersion method for appropriate period, that is, 7, 14, 21, or 28 days. The data obtained was subjected to statistical analysis (TWO WAY ANOVA) to test for the significant difference in compressive strengths of the different curing delays and the curing ages of the concrete.

RESULTS AND DISCUSSION

Figures 2 through 5 show the graphical relationships between average compressive strengths of concrete and curing delays at curing ages of 7, 14, 21, and 28 days for curing delays of 0, 1, 2, 3, and 4 days, with the zero day curing delay serving as the control. Prescribed mix ratios of 1:1.5:3 and 1:2:4 with the water/cement ratios of 0.5 and 0.6 were used. The results revealed that strengths of the concrete increase with increase in curing age with significant difference at 95% confidence level ($F = 829.76$; $F = 239.49$; $F = 310.06$; and $F = 318.20$ for 1:1.5:3, 0.5 w/c; 1:1.5:3, 0.6 w/c; 1:2:4, 0.5 w/c; and 1:2:4, 0.6 w/c respectively, all of which are greater than $F_{crit} = 3.259$). This might be as a result of hydration reaction of C_3S and C_2S and water to produce C – S – H which is responsible for the gain in strength of concrete. This finding was in agreement with what Ye, Zollinger, Choi, & Won, (2006) reported.However, compressive strengths reduce with increase in water/cement ratio; this might be that more water evaporates from the mix with higher water/cement ratio. Consequently, more void spaces need to be filled by the hydration products, insufficient of which might lead to leaving more empty void spaces, and consequently leads to the reduction in strength of the concrete, that is, as a result of weak bonding. Similar finding was reported by Ye, Zollinger, Choi, & Won, (2006) and Shetty, (2005). It was also observed that delaying curing of concrete adversely affect the compressive strength of the concrete (Figures 6 – 9). Strengths of concrete decrease with increase in age of curing delay, but slowly recover with the increase in the age of curing of the concrete. That is, percentage reduction in compressive strengths of the concrete increase strongly correlated with length of period of curing delay and negatively correlated with the age of curing. This might be that, at early ages the concrete core still contains some water for the hydration process to continue even though not sufficiently available for the full hydration reaction. As the age of curing delay prolongs, the water in the concrete would be getting exhausted by the hydration reactions as well as evaporation. It might reach a point when the relative humidity within and outside the concrete would be below 80% and the hydration reaction would cease as reported by Neville, (1997). Even though, the strength is somehow recoverable as reported by Aminur, Harunur, Teo, and Abu Zakir, (2010), but since at the age of 28 days the concrete could not recover fully, it might be inferred that the concrete suffered irrecoverable loss of compressive strength which was in accordance with what Al-Ani and Al-Zaiwary, (1988) reported. It might be that there was partial blockage of the surface capillaries of the concrete as a result of conversion of calcium hydroxide to calcium carbonate because of evaporation of pore water in the concrete as inferred by Newman and Choo, (2003). The consequential calcium carbonate that partially blocks the capillaries makes it difficult to get water back into the concrete.

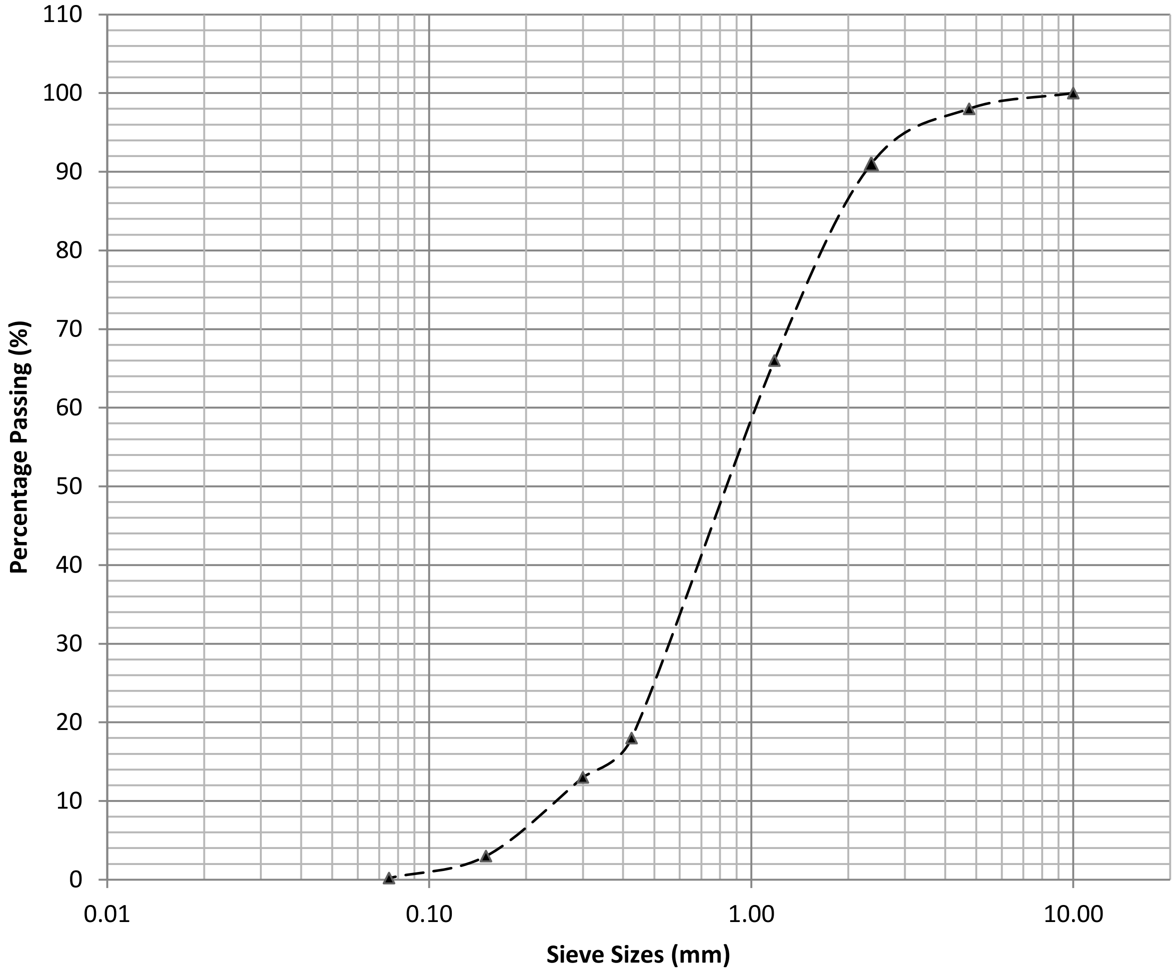

Figure 1: Sieve Analysis for the Fine Aggregates (Sand)

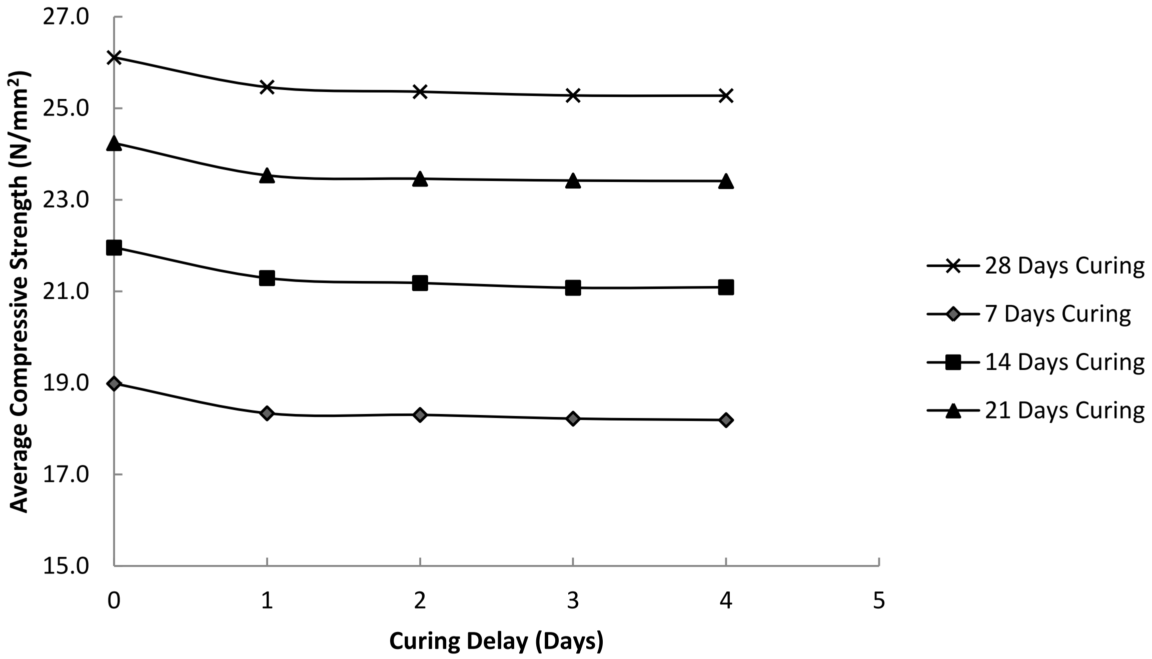

Figure 2: Relationship between Curing Delays and Average compressive Stress at Different Curing Ages for 1:$1\frac{1}{2}$:3 mix at 0.5 W/C ratio

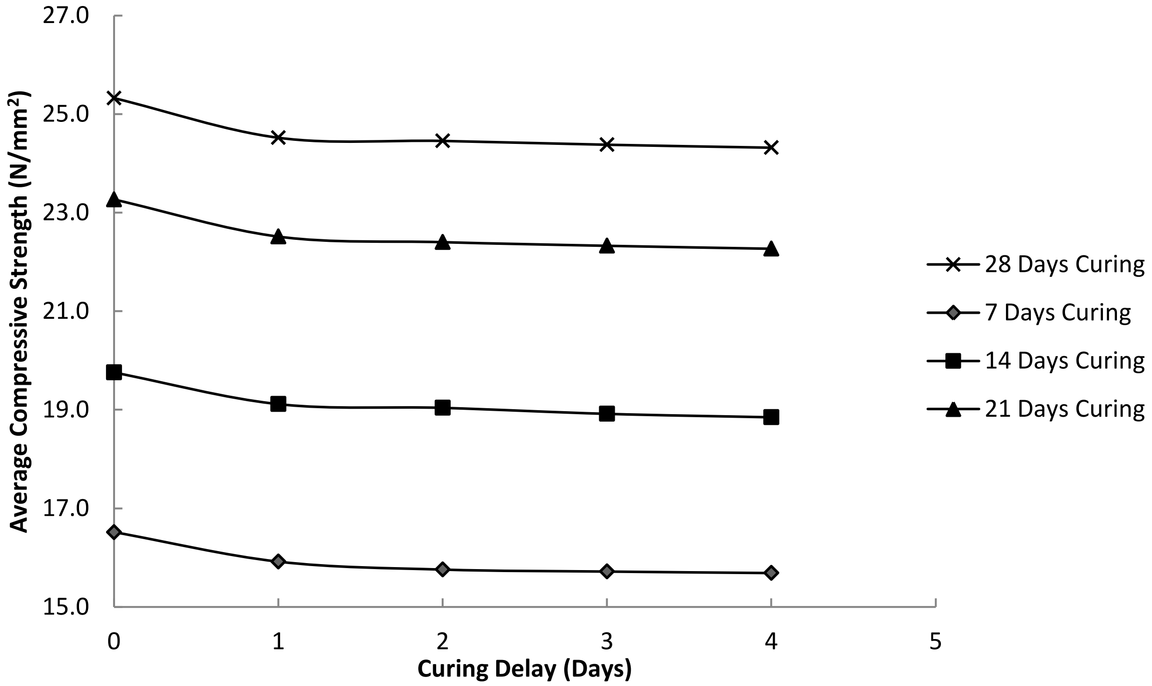

Figure 3: Relationship between Curing Delays and Average compressive Stress at Different Curing Ages for 1:$1\frac{1}{2}$: 3mix at 0.6 W/C ratio

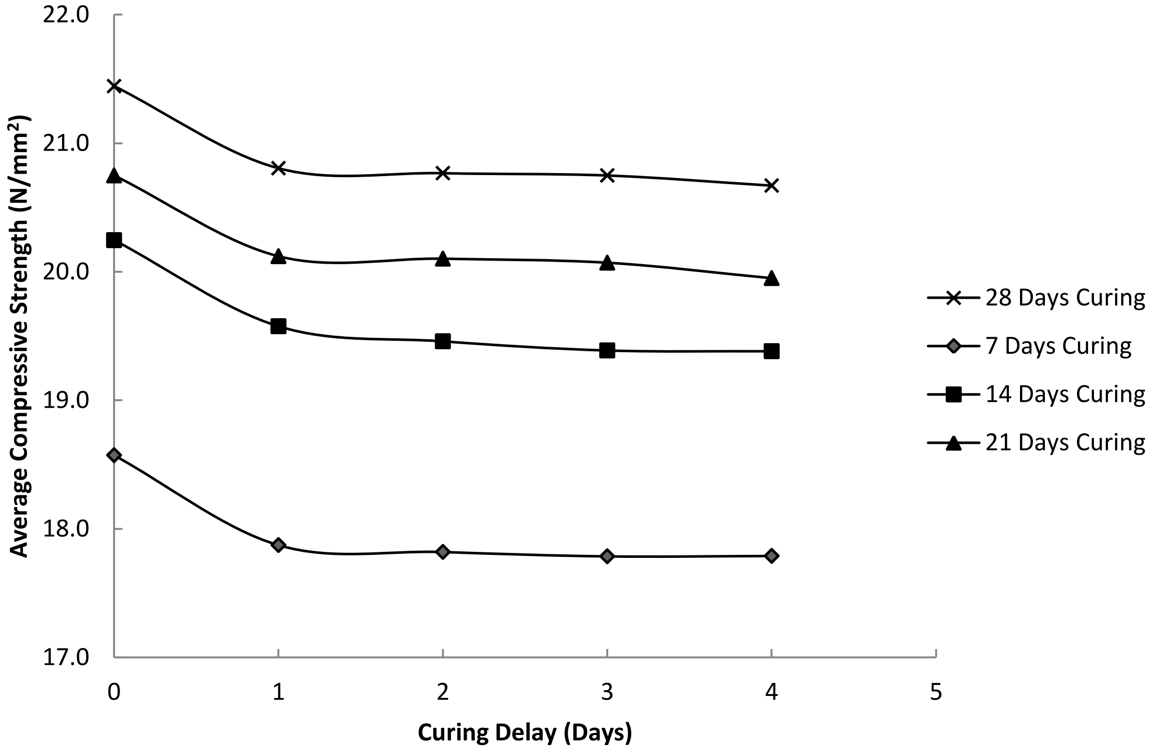

Figure 4: Relationship between Curing Delays and Average compressive Stress at Different Curing Ages for 1:2:4mix at 0.5 W/C ratio

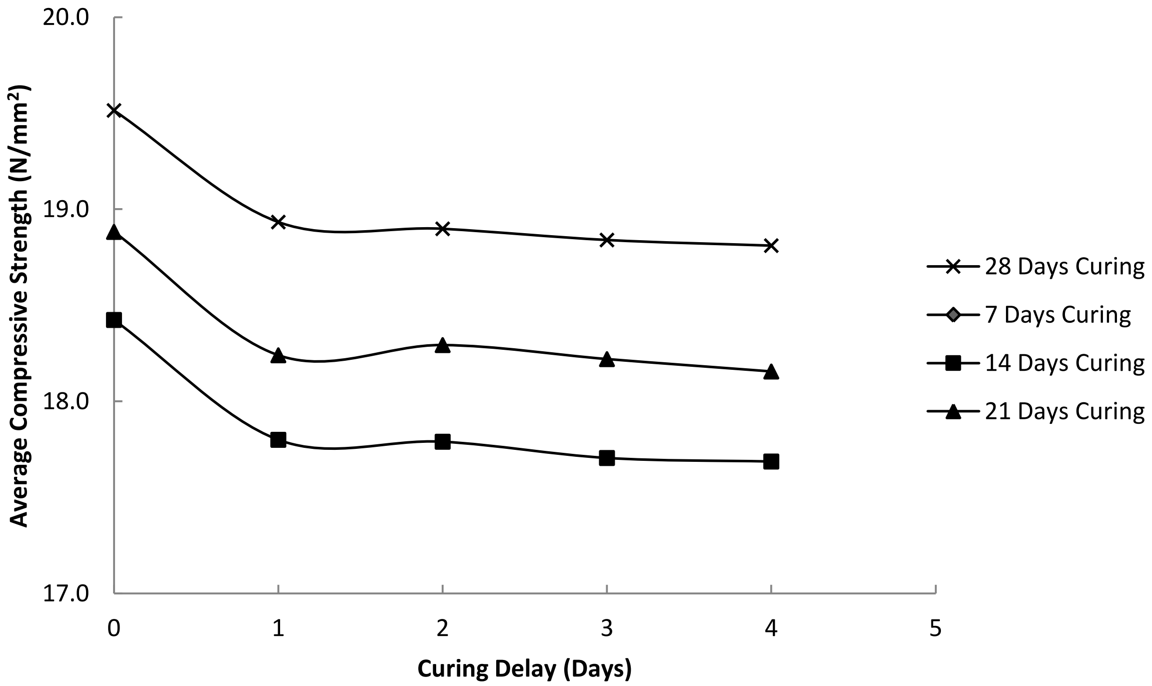

Figure 5: Relationship between Curing Delays and Average compressive Stress at Different Curing Ages for 1:2:4 mix at 0.6 W/C ratio

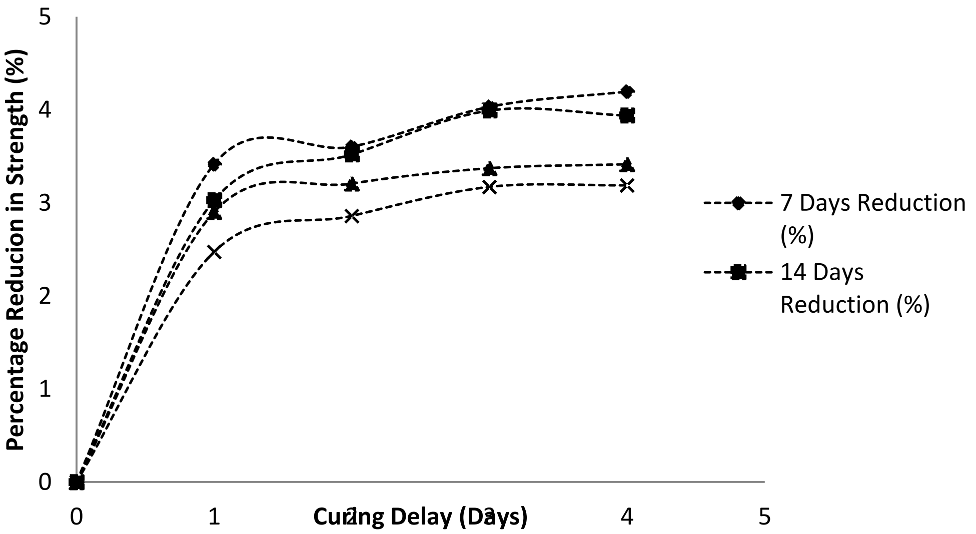

Figure 6: Relationship between Age of Curing Delay and Percentage reduction in Compressive Strength for Concrete with W/C ratio of 0.5 and Mix ratio of 1:1.5:3 at Various Ages of Curing

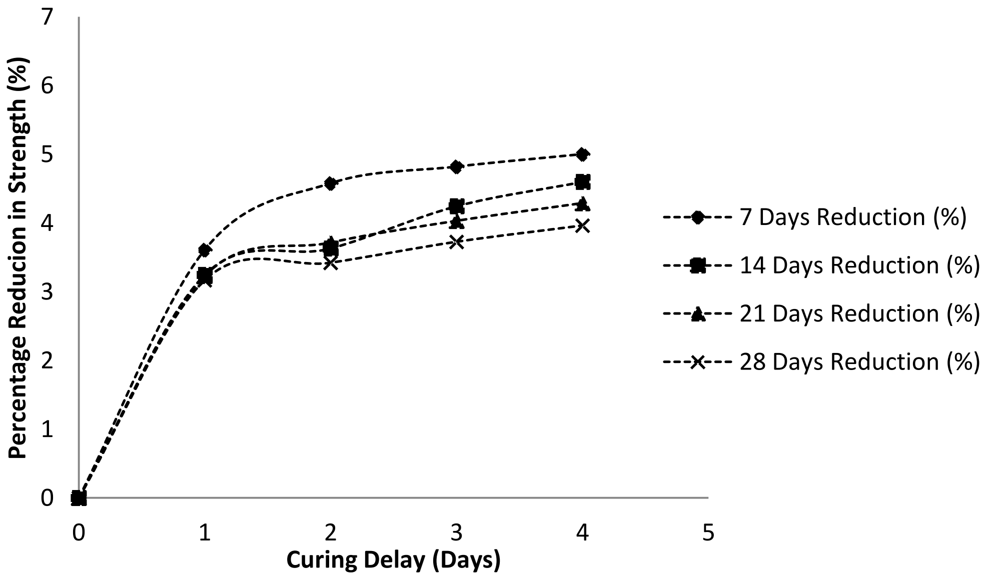

Figure 7: Relationship between Age of Curing Delay and Percentage reduction in Compressive Strength for Concrete with W/C ratio of 0.6 and Mix ratio of 1:1.5:3 at Various Ages of Curing

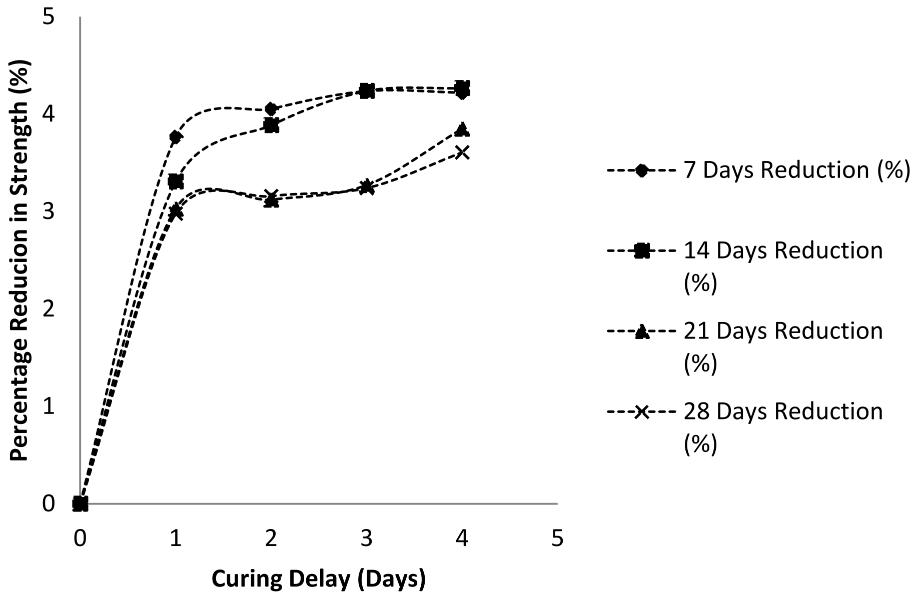

Figure 8: Relationship between Age of Curing Delay and Percentage reduction in Compressive Strength for Concrete with W/C ratio of 0.5 and Mix ratio of 1:2:4 at Various Ages of Curing

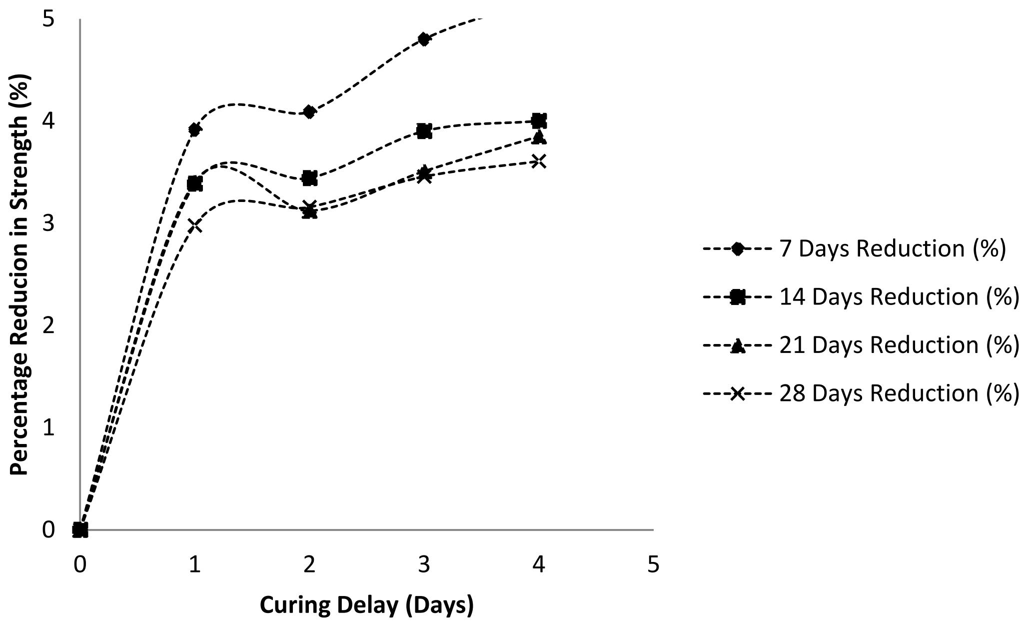

Figure 9: Relationship between Age of Curing Delay and Percentage reduction in Compressive Strength for Concrete with W/C ratio of 0.6 and Mix ratio of 1:2:4 at Various Ages of Curing

CONCLUSION

Based on the results of the tests obtained and discussed, the following conclusions were drawn:

1. The compressive strength of concrete increases with age of curing
2. The longer the curing delay, the higher the damage incurred on the strength of concrete
3. Delay in initial curing inflicts irreversible loss of compressive strength of concrete
4. The higher the grade of concrete the lower the loss in compressive strength as a result of curing delay
5. The higher the water/cement ratio, the higher the loss in compressive strength as a result of curing delays.

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