# Non-standard Curing Methods Effects on Compressive Strength of Fly Ash Concrete

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**Abstract**

The aim of the present study was to assess the effects of various curing methods on the compressive strength of concrete commonly utilized in Botswana. Towards this end concrete was manufactured using Botcem cement, 13.2 mm coarse aggregate and river sand, all procured locally. The curing methods employed were sand curing, water curing or immersion, and plastic curing or cling wrapping. Three different conventional water-cement or w/c ratios 0.5, 0.6 and 0.7 were employed, and the compressive strength of the concrete was ascertained at 7, 14 and 28 days of curing. It was found that the compressive strengths of the sand cured concrete specimens were generally higher than those of the water cured or plastic cured samples for all ages of curing and w/c ratios. These results were in agreement with those reported by some investigators in the literature; for the relatively few researchers whose findings were contrary, a number of factors were adduced or suggested to account for the apparent anomaly.

***Keywords:*** *Curing, Concrete, Water-Cement Ratio, Compressive Strength, Fly Ash*

## 1. Introduction

Curing of concrete according to Neville (2011) describes the techniques involved in developing or enhancing the hydration of cement, and entails a control of temperature and moisture movement from and into the concrete. It has been emphasized that hydration is readily facilitated only under conditions of saturation and is retarded almost completely when the vapour pressure of water in capillaries falls below 80% of the saturation humidity. Consequently, time and humidity are important factors, as well as temperature, since hydration involves a chemical reaction (Mehta and Monteiro, 2006).

The benefits of adequate curing are numerous, as it aids in the attainment of the desired strength and durability, and assists in minimizing volume changes in the concrete due to shrinkage (Mindess et al., 2003). These considerations are of crucial importance given that the demand for concrete is likely to greatly exceed 10 billion tonnes yearly in the near future (Meyer, 2009). Conversely the implications of improper curing are inadequate strength, drying and shrinkage of concrete, formation of cracks and poorly segmented capillaries.

The effects of climate change in the last few decades have meant that the drying of the earth's land surface has been significantly accelerated. This has produced attendant problems such as increasing temperatures, higher evaporation rates, severe droughts, a reduction in soil moisture and increased arid zones covering a considerable proportion of the earth's land surface (US Environmental Protection Agency, 2017). In consequence, water sources for use in the construction industry have become severely depleted. A by-product of this as far as the concrete manufacturing industry is concerned is that interest in alternative curing methods for concrete other than the traditional ponding or immersion has increased considerably. Some of such approaches include the use of wet coverings to maintain the availability of water for curing concrete, the use of plastic sheets or cling wrapping, sand curing to prevent the loss of water from concrete by sealing its exposed surfaces, use of lime curing, employing linseed oil as curing agent, use of saw dust, etc. The present research is concerned with a comparative study of the compressive strength of concrete based on three different curing methods, namely, water curing by immersion, use of plastic sheets or cling wrapping and sand curing.

A number of important or significant researches in respect of alternative curing techniques have been reported in the literature. Tariq et al. (Department of Civil Engineering, University of Engineering and Technology, Lahore, Pakistan, Unpublished results) and subsequently Anwar et al. (2022) compared four curing methods – air, water submersion, polythene wrapping and boiling, for concrete mixes 1:1.5:3 and water-cement or w/c ratio of 0.5. Testing of cube specimens was carried out at 3, 7, 14, 21 and 28 days. They concluded that the water immersion technique produced the highest 28-day compressive strength and recommended the restriction of the other curing methods to a 28-day time frame. Raheem et al. (2013) utilized a 1:2:4 concrete mix, a w/c ratio of 0.65 and six curing methods –air, water immersion, spray, polythene sheet, moist sand and burlap; testing of hardened cubes was done at 3, 7, 14, 21 and 28 days. Their results demonstrated that the moist sand curing method gave the maximum 28-day compressive strength followed by the burlap technique. Nevertheless, all curing methods apart from air curing met the minimum specified compressive strength.

Akinwumi and Gbadamosi (2014) used a concrete mix of 1:2:4 by volume, with a w/c ratio of 0.5 and five curing methods – immersion in water and lime water, covering in wet rug and plastic sheets, and air curing. Testing of cube specimens was carried out at 3, 7, 14, 28 and 90 days. They suggested that the use of air covering should be discouraged and all other curing methods restricted to the 28 days time frame. Interestingly, the lime water immersion approach produced the highest compressive strengths while wet rug curing gave the least values. Usman and Isa (2015) used concrete mixes of 1:2:4 and 1:3:6 with a w/c ratio of 0.55, and four curing methods – water immersion, sprinkling, polythene sheeting and sharp sand curing. Testing of concrete specimens was effected at 3, 7, 21 and 28 days. The water immersion and the sprinkling or spraying technique resulted in the most satisfactory compressive strength, while the use of sharp sand gave the least values. However it should be noted that these results may not be too reliable given that batching of the concrete mixes was by volume. As noted by Kellerman (2009), this method of proportioning is liable to introduce a number of possible errors into the investigation. In addition the sharp sand used in the study of Usman and Isa (2015) might not have been consistently wet throughout the curing period, given the relatively high temperatures prevailing in the geographical region where their investigations were conducted.

Yahaya et al. (2015) investigated the effect of curing regime on the compressive strength of aerated concrete containing palm oil fuel ash as partial sand replacement. Testing was conducted at 7, 14, 28 and 90 days. Three curing methods were employed – water curing, initial water curing for 7 days followed by air curing, and air curing. They concluded that curing methods affect the compressive strength of aerated concrete containing palm oil fuel ash and recommended water curing as the most suitable method to guarantee strength development. Obam (2016) used a 1:2:4 concrete mix with a w/c ratio of 0.51 and three curing methods – ponding or immersion, wet rug covering and polythene sheets. The 28-day test results demonstrated that cubes cured by immersion yielded compressive strengths that were about 10.8% and 20.2% higher than specimens cured by wet rug and polythene sheeting respectively. Olofinade et al. (2017) conducted an investigation involving concrete containing crushed waste glass as substitute for natural aggregates. Two curing methods were employed – total immersion in water and plastic membrane sheet covering. A 1:2:4 concrete mix and w/c ratio of 0.5 was used. They found that specimens cured in water gave higher compressive and tensile strengths than their counterparts cured using polythene sheets. Arslan et al. (2017) investigated the strength of concrete cylinders at 3, 7, 10, 14 and 28 days using a concrete mix proportion of 1:1.5:2.5 and a w/c ratio of 0.45. Three different curing regimes – open air, water immersion and curing compounds, were employed. They observed that for all ages of testing, the specimens cured in water produced the highest compressive strengths.

Omuh et al. (2018) in their study of mixing and curing methods effects on the compressive strength of concrete compared cube strength results utilizing four curing techniques – water immersion, polythene sheet wrapping, open air curing and lastly, water immersion for 7 days followed by open air curing for 21 days. Two mix ratios were employed namely 1:2:4 and 1:1.5:3. The results revealed that for both concrete mix proportions, cube samples cured in water gave the most satisfactory compressive strengths. Prakash and Prasanthi (2018) reported studies on strength of concrete blocks comprising two mixes of 1:1.6:3.35 and 1:1.35:2.19 with w/c ratios of 0.45 and 0.29 respectively. Six curing techniques were utilized – air curing, water immersion, polythene wrapping, burlap curing, sand curing and lime curing. Testing was carried out at 7 and 28 days for M30 and M60 grade concrete. They found out that at 28 days for M30 grade concrete, lime curing gave the optimum values for compressive strength. However for M60 grade concrete at 28 days, moist sand curing produced the maximum compressive strengths.

Osei et al. (2019) utilized concrete mix ratios of 1:2:4 and 1:3:6 with a w/c ratio of 0.5 and 0.6 respectively. Four curing methods were employed – ponding, continuous wetting, open air and sprinkling with water; testing was carried out after 7, 14 and 28 days of curing. It was observed that for both concrete mixes, maximum 28-day compressive strengths were obtained for concrete cured by ponding. Also sprinkling, wet covering and open air methods did not satisfy the minimum specified compressive strength for the 1:2:4 mix at 28 days. Sidozian and Hamad (2019) compared the compressive and split tensile strengths of concrete specimens prepared using jute membrane, polypropylene curing and ponding. Mix proportions used were 1:2:4 by weight with a w/c ratio of 0.45, and testing was carried out at 7 and 28 days after curing.

Results revealed that for both compressive and split tensile strengths at 28 days, ponding produced the highest strength followed by polypropylene sheet and jute membrane in that order. Obhielo et al. (2020) used a 1:2:4 concrete mix with a w/c ratio of 0.6 and four curing regimes – water immersion, polythene sheet wrapping, saw dust and open air curing. Concrete cubes were tested at 7, 14, 21 and 28 days. Curing by immersion resulted in the highest 28-day strengths. However with the exception of air curing, all other methods met the minimum specified compressive strength. They recommended that polythene sheet wrapping would yield acceptable strengths in the absence of curing by immersion.

Raza et al. (2020) utilized ponding, sprinkling and wet rag covering with a 1:1.5:3 concrete mix and target strength of 25 MPa. Concrete cubes were tested at 3, 7, 14, 28 and 56 days. It was observed that although concrete specimens cured via ponding gave the highest compressive strengths at 28 days, the results for both sprinkling or spraying and wet cover curing were only marginally lower. Tripathi and Chandak (2020) conducted research on the influence of three curing methods – wet burlap, immersion and steam curing on M25 and M30 concrete. Concrete mix proportions of 1:1.72:2.96 with a w/c ratio of 0.48 was used for the M25 concrete, while 1:1.62:2.83 with a w/c ratio of 0.45 was used for the M30 concrete. They concluded that the optimum compressive strength was achieved using the immersion technique in comparison to the wet burlap or gunny bag method. However the difference in 28 day strengths for both curing methods was -2.77% and -4.66% for M25 and M30 concrete respectively. Karthik et al. (2020) investigated the strength characteristics of M25 and M40 grade concrete using the immersion, wet burlap or gunny bag and membrane curing employing pigmented emulsions of linseed oil as curing agent. The mix proportions for the M40 concrete were 1:1.67:2.92 while that of the M25 grade was 1:1:2, and for both mixes a w/c ratio of 0.5 was adopted. The 28-day test results revealed that immersion curing gave compressive strengths about 45.2% and 34.4% higher than values for gunny bag and membrane curing respectively for the M40 concrete; the corresponding increases for M25 concrete were 18.5% and 13.3% above the values for gunny bag and membrane curing respectively. Such margins appear to be much higher than those found by other investigators. Toklu and Yazicioglu (2020) investigated the effects of aggregate size and two curing techniques – water immersion and air curing, on the engineering properties of concrete such as the compressive strength, abrasion, etc. at 28 days. Aggregates in the range 0-8 mm and 0-16 mm were employed for concrete manufacture. For the 0-8 mm group, the compressive strength of the water cured samples was about 29% higher than he air cured counterparts; however for the 0-16 mm group, the water cured samples produced values of only 3% above the air cured equivalents.

Lawal and Agboola (2021) used a concrete mix proportion of 1:2:4 and five curing methods – membrane, covering with green leaves, ponding, sprinkling or spraying and natural air. Testing was carried out on hardened cubes at 7, 14, 21 and 28 days. They found that water curing was the most effective method and produced the highest compressive strengths. Notwithstanding, membrane curing was also recommended as an alternative method, although no indications were given in their tests as to how the sealing membrane was applied. Gabriel-Wettey et al. (2021) investigated the impact of curing methods on the porosity and compressive strength of concrete using a mix ratio 1:1.5:3 by weight and a w/c ratio of 0.6. Four curing methods were employed namely immersion, jute sack, plastic sheet wrapping and sprinkling. Testing of cubes was carried out at 7, 14, 21, 28 and 56 days. They concluded that both compressive strength and concrete density are a function of curing methods and that immersion curing yielded the highest strengths as well as the lowest porosity. Suresh (2021) studied the effect of different curing methods on long-term strength and durability of blended cement concretes using M20 and M25 concrete grades, and four main curing methods – immersion, wet sand curing, use of curing compounds and water spraying. Compressive and flexural strengths amongst other parameters were assessed at 7 and 28 days. It was ascertained that concrete attained higher strength and durability with wet sand curing as compared to other techniques like immersion, application of curing compounds or spraying.

From the literature study it is obvious that although there has been considerable work carried out on curing techniques, there does not appear to be any definitive trend as per comparatively which method yields the optimum strengths. Furthermore not all curing approaches would be feasible or available in every circumstance. In addition the influence of geographical conditions cannot be discounted nor overlooked. In Botswana where there is some availability of sand albeit not too significant, but depleting sources of fresh water due to the influence of climate change mentioned earlier, some recourse has been made to the use of sand curing as an alternative. Consequently for the present study, three types of curing methods have been investigated – immersion, polythene sheeting or cling wrapping, and wet sand curing.

## 2. Materials and Methods

The cement used in the manufacture of concrete was Botcem supplied by PPC Cement Botswana. Botcem is a Portland fly ash cement that is suitable for general concrete work and where enhanced durability and reduced heat of hydration is required. It is made by intergrinding controlled amounts of siliceous and calcareous fly ash with Ordinary Portland Cement. The intergrinding process is unique to PPC, and allows for the fineness of Botcem to be carefully controlled to give consistent performance in the 32.5N strength class. More specifically, Botcem Portland Cement CEM II/B-W 32.5R (Cement and Concrete Institute, 2014) containing between 21% - 35% calcareous fly ash, and manufactured in accordance with SANS 50197-1/EN 197-1 (2013) was employed. The fine aggregate used was a locally available river sand from Moshupa passing through a 4.75 mm sieve and possessing a fineness modulus of 3.2. The coarse aggregate was 13.2 mm maximum crushed size obtained from Kgale Quarry. Fresh potable tap water with a pH value of 7.0 was used for the investigation.

The Structures and Materials laboratories of the Department of Civil Engineering at the University of Botswana were used in the preparation and manufacture of the concrete mixes. The mix design and proportioning were in accordance with the Portland Cement Institute (PCI) method of concrete mix design derived primarily from ACI 211.1-89 as described by Addis and Goodman (2009). Three concrete mixes were designed reflecting different water-cement or w/c ratios of 0.5, 0.6 and 0.7; the proportions for a cubic metre of fresh concrete are shown in Table 1. Additional details related to the mix design can be found in the work of Moji (Department of Civil Engineering, University of Botswana, Gaborone, Unpublished results).

Table 1: Control mix proportions in kg for 1 cubic metre of fresh concrete

| Botcem Cement | Coarse Aggregate | Fine Aggregate | Potable Water |
|---|---|---|---|
| 440 | 1032 | 683 | 220 |
| 440 | 1032 | 683 | 264 |
| 440 | 1032 | 683 | 308 |

The concrete was mixed in a laboratory mixer; initially the cement, fine and coarse aggregates were mixed together for a period of two minutes prior to water being added and further mixing. For each mix proportion, twenty-seven 150 mm moulds were used. All concrete mixes were placed in two layers in each mould and thereafter compacted on a vibrating table. After casting, all specimens were allowed to set for 24 hours, and subsequently demoulded and cured using the different curing methods specified earlier, namely immersion in water, wet sand curing and plastic or cling wrapping. In respect of water curing, the cubes were immersed in a water tank and a temperature of between 22ºC and 25ºC was maintained. However there was a little difficulty in adhering to this temperature range throughout the curing period and some intervention was necessary from time to time. With regards to sand curing, the concrete specimens were laid 150 mm apart on alternate 150 mm thick layers of wet sand and covered with a final layer of wet sand of the same thickness. Metal dustbins were utilized for this purpose. With reference to plastic curing, the individual specimens were wrapped with a cling wrapper. The different curing methods utilized in the investigation are illustrated in Figures 1 to 3 in respect of water immersion, wet sand curing and cling wrapping respectively.

Fig. 1: Concrete cubes immersed in a water tank

Fig. 2: Concrete cubes covered with wet sand in a bin

Fig. 3: Concrete cubes covered with plastic wrapping

The compressive strength of the hardened concrete specimens were determined after 7, 14 and 28 days of curing for all w/c ratios and curing methods. Procedurally, before crushing, each cube was wiped dry to remove any surface moisture. Testing was done using a uniaxial compression testing machine, as shown in Figure 4. The concrete specimens were each centrally placed between the platens of the machine with the trowelled face sideways. The load was applied at a constant rate of 0.3 MPa/sec up until cube failure, in accordance with the South African standard SANS 5863: 2006. The loads to cause ultimate cube crushing, as well as the cube failure patterns were noted in all cases.

Fig. 4: Uniaxial compression testing machine

## 3. Results and Discussion

The variation of compressive strength with age for the three methods of curing, that is, water immersion, wet sand curing and plastic or cling wrapping are shown in Figures 5, 6 and 7 respectively. It can be observed that regardless of the curing age or the method of curing, the specimens with a w/c ratio of 0.5 produced the highest strengths, followed by those concrete cubes with a w/c ratio of 0.6 and then 0.7 in that order. This trend is generally accepted in the literature and no further comment will be made in this regard. Of interest however is the fact that for both water immersion and plastic wrapping their respective strengths for w/c ratios of 0.6 and 0.7 are close to one another, in contrast to the strengths for w/c ratio of 0.5. In the case of sand curing however the results for a w/c ratio of 0.6 falls roughly half way between the strengths for w/c ratio of 0.5 and 0.7.

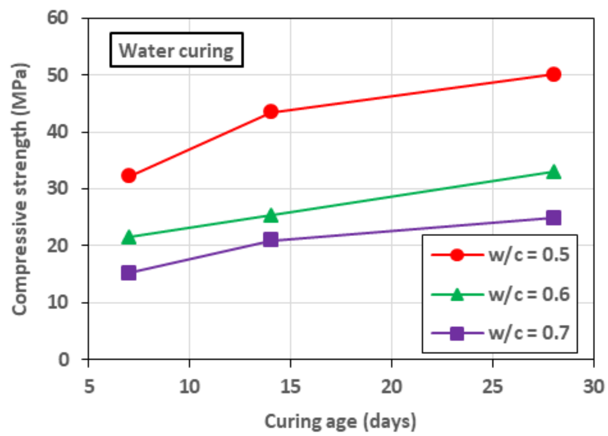


Fig. 5: Variation of compressive strength with age (water curing)

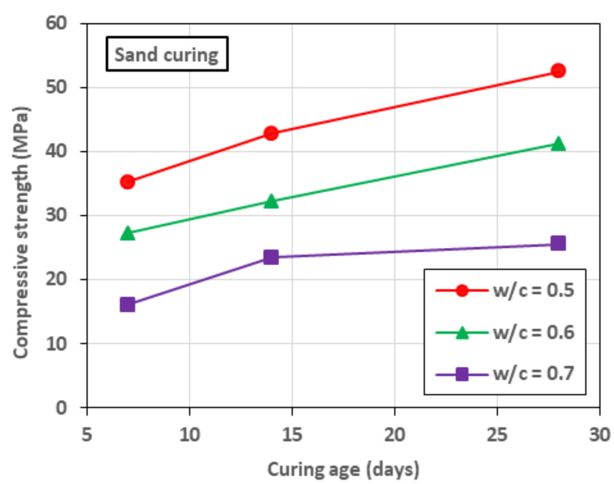


Fig. 6: Variation of compressive strength with age (wet sand curing)

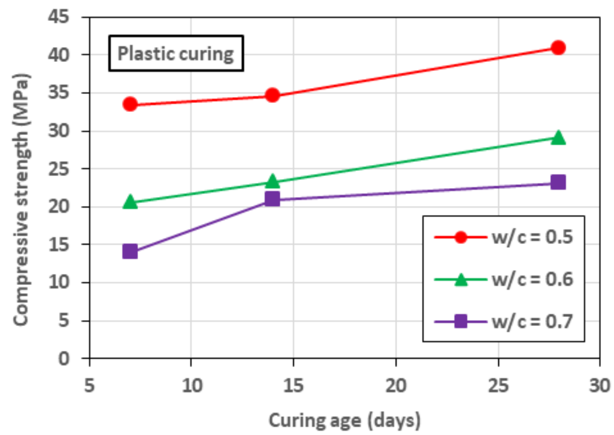


Fig. 7: Variation of compressive strength with age (plastic curing)

The variation of compressive strength with w/c ratio for all curing methods at 7, 14 and 28 days are shown in Figures 8, 9 and 10 in that order. Again as noted previously, the graphs show a progressive decrease in strength from a w/c ratio of 0.5 to a w/c ratio of 0.7 as expected. In general, the strength profiles of specimens cured by water immersion lie in between those of cubes cured by wet sand and plastic wrapping. Specimens cured by moist sand yielded consistently the highest strengths while those cured by cling wrapping gave the lowest strengths. As an example, for a w/c ratio of 0.5 at 7 days, the strength for specimens cured by sand, water and plastic sheeting were 35.2, 32.2 and 33.4 MPa in that order. At 28 days for the same w/c ratio, the corresponding strengths were 52.5, 50.1 and 40.9 MPa. Also for a w/c ratio of 0.6 and testing at 7 days, the compressive strengths of sand, water immersion and plastic sheet cured specimens were 27.2, 21.5 and 20.6 MPa respectively; with testing at 28 days the corresponding strengths were 41.2, 33.0 and 29.1 MPa. Furthermore for a w/c ratio of 0.7 at 7 days, the strengths of the moist sand, water immersed and plastic wrapped cured specimens were 16.0, 15.2 and 14.0 MPa respectively. At 28 days the corresponding values were 25.6, 24.9 23.2 MPa. These results demonstrate that sand curing yielded the highest compressive strengths followed by water immersion and cling wrapping in that order.

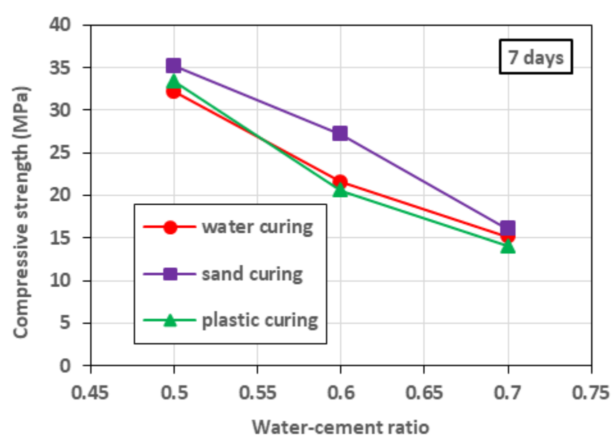


Fig. 8: Variation of compressive strength with w/c ratio at 7 days

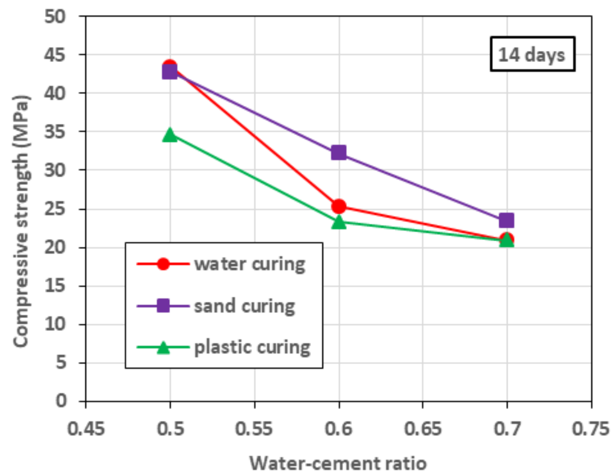


Fig. 9: Variation of compressive strength with w/c ratio at 14 days

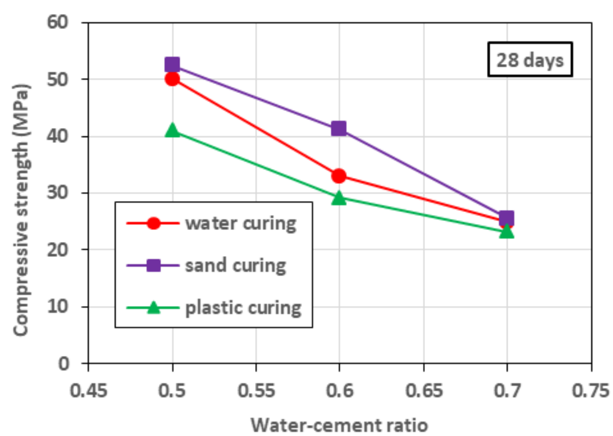


Fig. 10: Variation of compressive strength with w/c ratio at 28 days

The above findings are consistent with the results of Raheem et al. (2013), as well as Prakash and Prasanthi (2018) for M60 grade concrete at 28 days. For M30 grade concrete at 28 days, the results of Prakash and Prasanthi (2018) in respect of water cured and sand cured specimens were practically identical. Furthermore Suresh (2021) who used two concrete grades M20 and M25, and two main curing methods – water immersion and wet sand, concluded that moist sand gave superior strengths as compared to water immersion. However in contrast to the findings of the present research and other investigators just mentioned, Usman and Isa (2015) came to different conclusions. This was probably due to the fact that they utilized volume batching in their studies; as noted by Kellerman (2009) this method of proportioning is likely to introduce a number of possible errors into their investigation. In addition the relatively high temperatures prevailing in the geographical region where the tests of Usman and Isa (2015) were conducted could lead to their sand curing medium not being consistently moist throughout the curing periods. Consequently, their conclusions might not be too reliable.

To summarize all that has been stated regarding the results of the present investigation, it would appear that the use of moist sand curing represents a viable alternative to water immersion. This would be particularly useful in regions where there is ready availability of sand, or alternatively where there is some difficulty in obtaining supply of fresh potable water for curing purposes.

## 4. Conclusions

The present research has investigated the influence of non-standard curing methods on the compressive strength of fly ash concrete, or more specifically, concrete manufactured using Botcem cement as binder. Three curing methods have been adopted – water immersion, wet sand and polythene sheet wrapping. Tests on concrete cube specimens formed using w/c ratios of 0.5, 0.6 and 0.7 as well as the three curing procedures were conducted at 7, 14 and 28 days. Based on the work presented herein, the following conclusions have been reached.

Firstly, regardless of the w/c ratios adopted, concrete specimens cured using the wet sand method yield higher compressive strengths than those cured by water immersion or polythene sheet wrapping, irrespective of the age of testing. Secondly, these results were consistent with the findings of the majority of previous investigators who conducted comparative studies involving the moist sand curing technique. In addition, for the few researchers whose studies produced results contrary to those reported in the current investigation, detailed examination of their work suggest that their findings may not be too reliable for a number of reasons stated earlier on. Finally, the use of moist sand curing techniques represent a realistic and credible alternative to water immersion or ponding, more so where there may be problems obtaining supply of fresh potable water, or in relatively arid regions.

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