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Effects of Different Curing Methods on the Strength Development of Concrete Containing Waste Glass as Substitute for Natural Aggregate

Oluwarotimi M. Olofinnade[*, 1, a] **Anthony N. Ede1,**[b] **Julius M. Ndambuki**[2, c] **& David O. Olukanni1**[d]

[1]Department of Civil Engineering, Covenant University, Ota, Nigeria,
[2]Department of Civil Engineering, Tshwane University of Technology, Pretoria, South Africa
*,arotimi.olofinnade@covenantuniversity.edu.ng,
[b]anthony.ede@covenantuniversity.edu.ng,
[c]ndambukiJM@tut.ac.za,
[d]david.olukanni@covenantuniversity.edu.ng

Abstract – Concrete curing is fundamental to achieve quality and durable concrete. This study examines the influence of curing methods on the mechanical strength development of concrete comprises of waste soda lime glass pulverized into fine and coarse aggregate sizes as partial and complete replacement for natural aggregates in concrete. The primary variables considered are the curing methods. The glass content was varied in steps of 25% by weight from 0 – 100% to replace both natural fine and coarse aggregate in the concrete mixes. Concrete mixes were batched using a mix ratio of 1:2:4 (cement: sand: granite) at water-binder ratio of 0.5 targeting a moderate strength of 20 MPa. Forty-five (45) number concrete cubes and cylinders were cast and tested after 7, 14 and 28 days of curing using two curing methods; namely plastic membrane sheet covering and total immersion in water. The results obtained clearly indicate that waste glass concrete cured by complete immersion in water showed better performance in strength development than those cured by plastic membrane covering. Generally, the results indicate that concrete mix produced with 25% glass content exhibit significant strength that compared well with the control at 28 days of curing.

Keywords: Curing, Compressive strength, Natural aggregate, Waste glass, Split tensile strength

I. Introduction

Concrete is the most commonly used construction material and will continue to be in demand [1, 2]. Concrete is a combination of majorly two components (aggregates and binder) which through the process of hydration, the mixture hardens and gains strength. It is a material widely used for construction of buildings, drainage systems, bridges and road pavement networks, water dams, airfield runways, tunnel systems. However, in order to achieve good and quality concrete, the characteristic strength (compressive strength of the concrete mix and other mechanical properties) must be ascertained. According to [3], compressive strength of a concrete mix is a major index of its quality and it is important that concrete mix be developed beyond its minimum attainable design strength. Moreover, [4], stated that production of quality concrete required that the placement of a suitable concrete mix be followed by curing in an appropriate environment, especially at the premature stages of hardening. Furthermore, curing is one process used for facilitating the hydration of the cementitious binder in concrete, and this involves controlling the concrete environmental conditions; that is, the temperature and movement of moisture [5]. Curing is also referred to as a process of protecting the concrete for some specific duration of time after placement in order to ensure that concrete is not exposed to mechanical disturbance at the early age. This process helps to ensure that concrete retains enough moisture and temperature necessary for hydration which leads to continued strength development [6]. The influence of curing temperature on the strength properties of concrete has been studied in recent times [2] – [11]. Neville and Brooks [4], explained one of the needs for curing arises from the fact that complete hydration of cement can only take place in water-filled capillaries. In addition, provided the concrete is properly cured, the strength of concrete increases with time due to improved degree of hydration. However, Li [2] stated that the concrete strength will continue to go up even after 28 days of curing but the progress of cement hydration under real life conditions may vary greatly from site to site. Furthermore, curing process ensures concrete durability, improves porosity, resistance to abrasion, resistance to freezing and thawing, resistance to chemical attacks, volumetric stability; reduce creep and shrinkage, reduces powdery deposition on concrete surfaces and prevents crazing [5,10,12]. Various methods of curing includes immersion in water, sprinkling, the use of wet coverings, the use of membrane forming compounds, plastic sheet covering and open air curing. Mamlouk et al. [12] stated that factors such as environmental condition, cost implication, size and shape of the concrete structure, availability of curing materials, supervision and aesthetics are considered before adopting any curing method. Many investigators have studied the effect of curing conditions on the strength development of plain and blended cement concrete [13], ordinary concrete [7], [14-17], concrete containing supplementary cementitious materials (SCM) [8-9], [18-21], high-performance concrete [22], self-compacting concrete [23-25] and concrete under hot weather conditions [11]. However, of recent, the sustainability of concrete as a building material has become a critical issue [26-27]. The production process of concrete consumes much of the natural resources and energy. For instance cement is a major constituent of concrete and its production is regarded as one of the major sources of greenhouse gas (GHG) emission into the atmosphere [27]. Meyer [28] estimated that the demand for concrete is expected to increase to about 18 billion tonnes by the year 2050. However, Terro [29] and Olofinnade et al. [30] opined that reusing and recycling of solid wastes such as waste glass in concrete by the construction industry can help sustain and protect the environment through elimination of waste materials that could have been a concern to the environment. Furthermore, the use of waste glass as concrete aggregate can minimize environmental degradation through depletion of the raw resources. Many studies have investigated the effect of replacing aggregates in concrete with waste glass on the mechanical properties of the concrete [31] – [36]. The methods of curing adopted in most of these cases is total immersion in water. In addition, Rashad [35] reported that of recent, there is an increase in the quantity of glass production and usage. This has resulted in the huge amount of glass waste generated and dumped into dump sites [35] – [37]. However, incorporating these glass waste as aggregate in concrete has the potential to reduce the amount of glass waste in dump sites and also reduce the depletion of natural resource [28-36]. Therefore this research examines the strength development of moderate strength concrete produced with and without crushed waste soda lime glass as sand and granite replacement. The concrete samples were cured by complete immersion in water and covering with polythene sheets for 7, 14 and 28 days.

II. Materials and Methods

Materials

Ordinary Portland Cement (OPC) (ASTM Type I) and natural aggregate used for production of concrete in this study were obtained commercially. The chemical compositions of the Portland cement is presented in Table 1. The soda lime glass wastes were collected from open dump sites and glass waste gathering points in Ota, Ogun State, Nigeria. Dumping of solid wastes such as glass wastes within Ota metropolis is mostly practiced through dumping on open sites [37]. The major portion of such waste glass comprises mostly beer, perfume and wine bottles, glass wares, flat glasses, and glass containers. The waste glasses were carefully washed with water to remove dirt and contaminants such as paper labels, rubber corks and metals, and air dried before the glasses were then pulverized to required particle sizes similar to the natural fine and coarse aggregate sizes using a mill crushing machine. The chemical composition of the waste glass were obtained by using the X-ray fluorescence (XRF) techniques in order to determine the oxide composition of the glass as presented in Table 1. Potable water was used for mixing and curing of concrete specimens.

Table 1: Chemical compositions of Portland cement and waste glass

Composition	**SiO_2**	**Al_2O_3**	**Fe_2O_3**	**CaO**	**MgO**	**K_2O**	**Na_2O**	**TiO_2**	**Cr_2O_3**
Glass (% wt)	64.31	2.98	6.25	10.61	0.63	0.74	12.52	0.61	0.23
Cement (% wt)	21.08	5.40	6.28	60.25	3.96	0.85	0.33	0.62	-

Table 2: Physical properties of the natural and waste glass aggregates

Material Properties	**Natural aggregate**		**Waste glass aggregate**		**Water**	**ement**
	Sand	Granite	Coarse	Fine		
Specific gravity	2.63	2.70	1.93	2.50		
Fineness Modulus	2.69	2.85	2.72	2.99		3.15
Water absorption (%)	2.28	0.25	0.36	0.4		
Unit weight (kN/m^3)	16.04	24.12	23.57	22.37	9.81	14.12
Initial setting time (min)						68
Final setting time (min)						185

Material Preparation

For preparation of the concrete mix, river sand of sieve size 0.075 mm – 4.75 mm and crushed granite of maximum aggregate size of 20 mm mixed with the cement (binder) were used to produce the reference concrete specimens and other concrete mixes containing waste glass used for this research work. Figure 1 depicts the sieve analysis showing the particle size distribution of the river sand, granite and crushed waste glass while Table 2 reveals the physical properties of the natural aggregate and crushed waste glass aggregate used in this study. All mixtures were batched by weight, using a mix ratio of 1:2:4 (cement: sand: granite) and a water-binder ratio of 0.5. The design strength targeted in this study is 20 MPa at 28 days curing period. Four (4) resulting mixtures were produced by blending the pulverized waste glass aggregate as substitute for both the natural fine and coarse aggregates in the same mixture in proportions of 25%, 50%, 75% and 100%. Table 3 shows a summary of batching for the mix ratio by weight.

Preparation of Test Specimens

A total of 45 cube specimens of dimension 150 x 150 x 150 mm and cylinder specimens of 100 mm diameter by 200 mm in height were cast in mold, kept in a cool place and removed after 24±2 hours. Each specimen was filled in three layers and tampered 25 times to remove entrapped air and was appropriately labelled for identification.

Table 3: Batching of Concrete

Material Batching (kg)	Percentage Glass Content				
	0	25	50	75	100
Water	138	138	138	138	138
Cement	275	275	275	275	275
Natural fine aggregate	550	413	275	138	0
Natural coarse aggregate	1100	825	550	275	0
Waste glass coarse aggregate	0	275	550	825	1100
Waste glass fine aggregate	0	138	275	413	550

Curing Methods

The concrete specimens were cured in the laboratory under two types of curing conditions before testing. The first method was curing by total immersion in potable water (WC) at mean daily temperature that ranged from 28 – 32°C all through the period of curing with mean relative humidity that ranged from 60 – 85%. Secondly, curing by wrapping the concrete specimens with polythene nylon sheets (PC). The edges of the sheets were fastened together with tapes to prevent loss of moisture from the concrete surface.

Testing of the hardened concrete

The hardened concrete were tested for compressive- and split tensile-strength at ages of 7, 14 and 28 days for each percentage replacement of both natural fine and coarse aggregate with crushed waste glass aggregate content in the same concrete mix. The average strength of three specimens were determined for the various tests. The compressive and the split tensile strengths of the concrete cubes and cylinders were determined in compliance with the provision of BS 12390 [38] using a digital display compression machine.

All materials and concrete specimens preparation and testing were carried out at the Structures and Material testing Laboratory of Civil Engineering, Covenant University, Ota.

III. Results and Discussion

Environmental Curing Conditions

Environmental factors such as moisture and temperature are vital environmental conditions considered in concrete curing. These factors affect the hydration process of the concrete and are usually not constant except in controlled environment [3]. Throughout the curing period in this study, the mean daily temperature and daily relative humidity in the laboratory, ranged from 28 to 32°C and 60 to 90%, respectively.

Particle Size Distribution of Materials

Figure 1 shows the result of the sieve analysis carried out on the sand, granite and crushed glass aggregate materials in order to determine the particle size distribution. The sieve plot for the sand used depicts a uniform gradation size (i.e. poorly graded). A larger portion of the sand particles are within medium to coarse range. The value of the uniformity coefficient and coefficient of curvature (Cc) calculated gives 3.25

and 0.94, respectively. Furthermore, based on the classification system used by the Unified Soil Classification System, uniformity coefficient (CU) less than 6 for sand indicates that grain sizes were of uniform size that is; poorly or uniformly-graded. The particle size distribution for the granite particles also indicate that the particles were also uniformly graded. The gradation plots for the crushed waste glass aggregates shows uneven particle size distribution similar to the natural sand and granite aggregate. The particle size distribution of the glass and natural materials are closely equal.

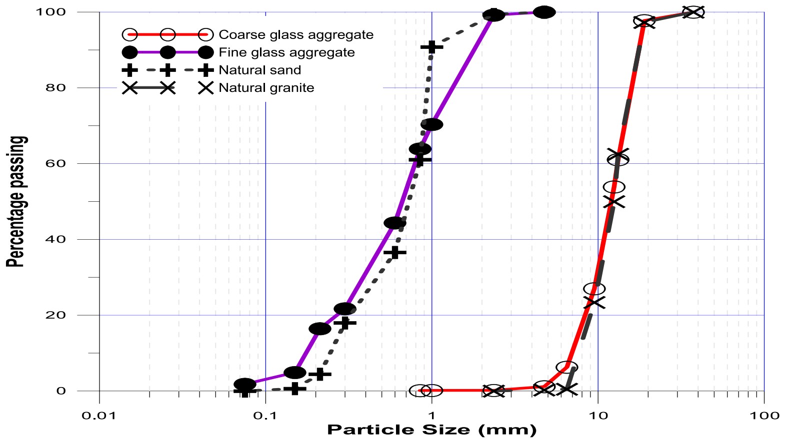

Figure 1: Sieve analysis for the waste glass, sand and granite material

Properties of Fresh Concrete - Slump

The obtained test result for the slump gives a value of 60 mm for the control mix, while the mixtures containing glass aggregate exhibit a reduction tendency in slump ranging from 20% to 22% reduction in concrete workability as the proportion of glass content increases. The results clearly indicate that workability of the concrete mixes decreases as the glass content increase from 25% to 100% as also reported by Olofinnade et al. [34]. The decrease in the slump may be attributed to the angular shape and geometry of the glass particles which reduces the fluidity of the mixes [39]. The concrete mixes were workable with no immoderate segregation.

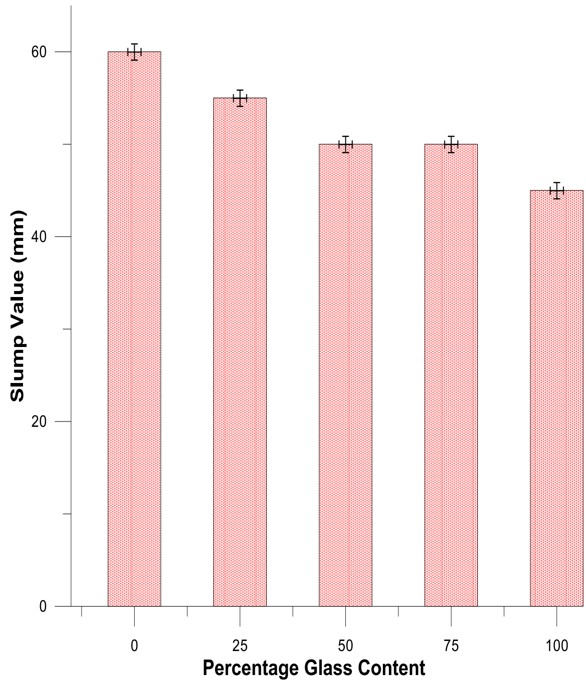

Figure 2: Changes in slump value with glass content

Compressive Strength

The results of the average compressive strength are shown in Figures 3 – 4, which depicts the average compressive strength against the curing age of the concrete cubes at ages 7, 14 and 28 days; for water curing and polythene sheet covering curing methods, respectively. As shown in Figures 2 and 3, the curves show clearly that the compressive strength development of all cube specimens increased with age; that is, the reference concrete and concrete cubes containing crushed glass content cured by immersion in water and polythene sheet covering increased in strength as the period of curing increased for both curing conditions. However, it was observed in Figures 5, 6, and 7 that as the percentage substitution of both sand and granite with the glass content increases beyond 25% replacement, the compressive strength follows a steady decline in strength for all the curing medium at 7, 14 and 28-day testing, irrespective of the curing methods. The development of higher compressive strength was achieved through curing by total immersion in Water (WC). All the concrete cube specimens cured by total immersion in water performed better compared to those cured using the polythene sheet covering. This could be attributed to the sufficient moisture that is available for continued hydration of cement in the concrete as reported by Neville and Brooks [4] and Raheem et al. [40]. The control concrete and concrete containing crushed waste glass at 25% content were able to achieve the targeted minimum strength of 20 MPa at 28-day compared to the same concrete specimens cured by polythene sheet covering with a lower 28-day compressive strength of 17.78 and 18.67 MPa respectively. This result could be attributed to the inability of the concrete to have adequate access to external water to replace the used up internal water in the concrete pores in order to ensure 100% relative humidity as reported by [5]. Early drying of water in the concrete halts or slows down hydration process.

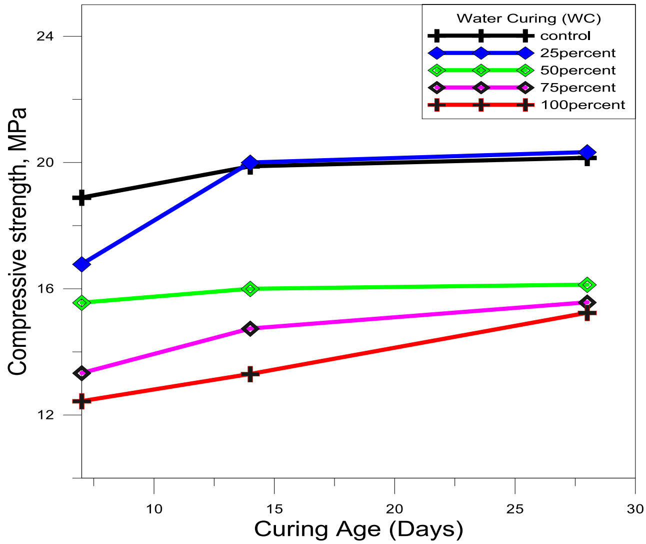

Figure 3: Compressive strength variation with curing age by immersion in water

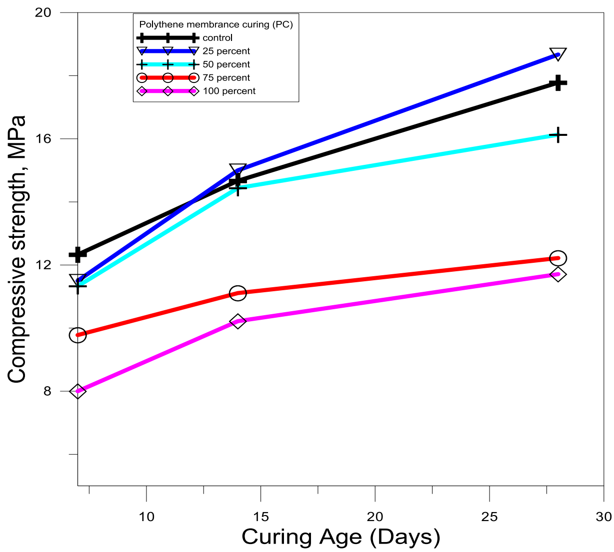

Figure 4: Compressive strength variation with curing age by polythene sheet covering

The concrete cube specimens recorded 80% of its 28-day strength just after 7 days of curing by immersion in water while curing with polythene sheet covering achieved 60% of its 28-day strength after 14-day of curing.

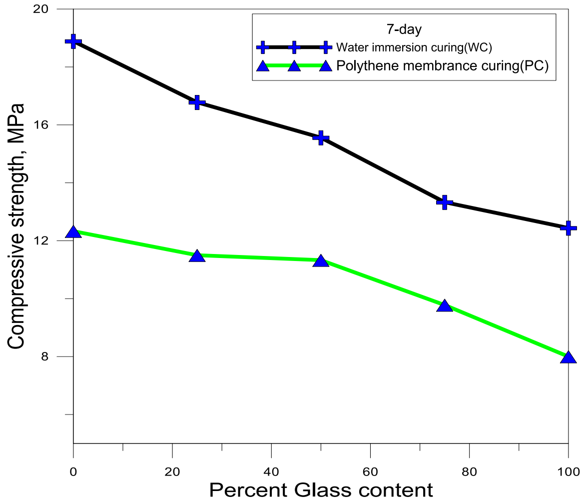

Figure 5: Comparison of compressive strength against glass content for 7-day and 14-day water and polythene curing

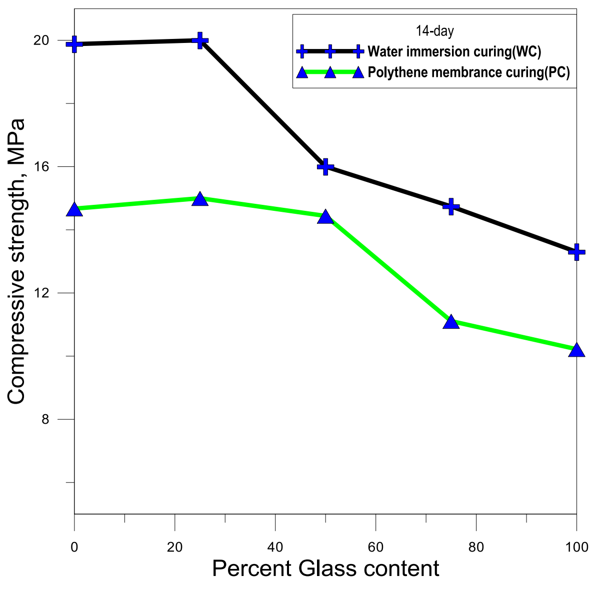

Figure 6: Comparison of compressive strength against glass content for 7-day and 14-day for water and polythene curing

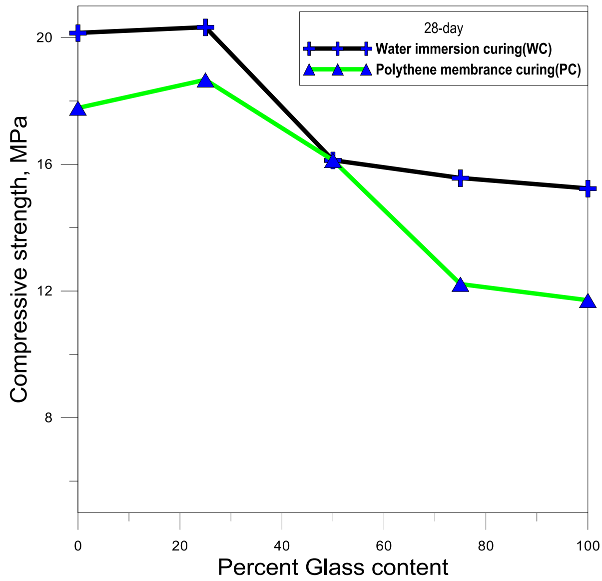

Figure 7: Comparison of compressive strength against glass content for 28-day water and polythene curing

Split Tensile Strength

The observed results for the average split tensile strength tests are presented in Figures 8 and 9 for 7, 14 and 28-day of curing by water immersion and polythene sheet covering respectively. The tensile strength test is used to evaluate the tensile stress resistance of the concrete. The tensile strength of concrete containing crushed waste glass at 25% glass replacement performed better compare to the control; exhibiting split tensile strength values of 3.09 and 3.50 MPa at 28-day for water curing and polythene sheet covering curing respectively, compared to tensile strength values of 3.80 and 3.25 MPa for the control. It was observed that the split tensile strength follows the same strength development trend exhibited by the compressive strength. Figure 10, 11 and 12 clearly depicts a reduction in the tensile strength development as the proportion of glass content increases for both the water curing method and curing by polythene covering sheet. However, all concrete specimens cured by water immersion performed better than those cured with polythene sheet covering. Generally, as expected there is a progressive increase in the tensile strength development over the curing period for both the water curing and polythene sheet covering curing methods.

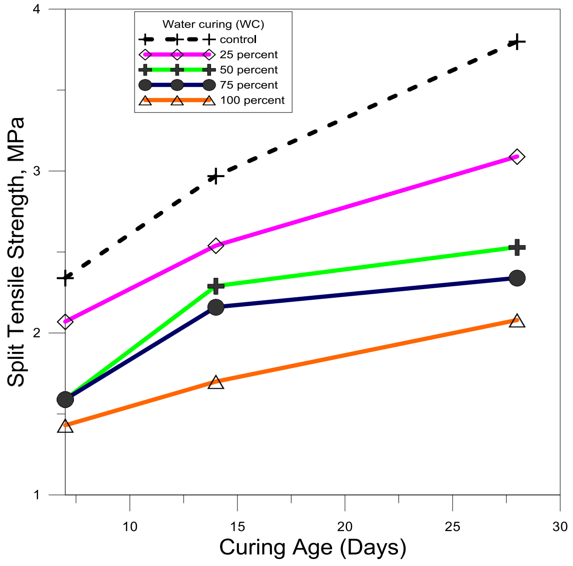

Figure 8: Split tensile strength variation with curing age by immersion in water

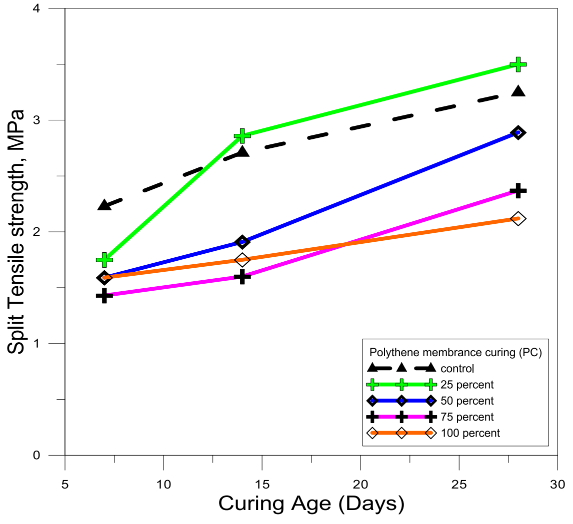

Figure 9: Split tensile strength variation with curing age with polythene covering

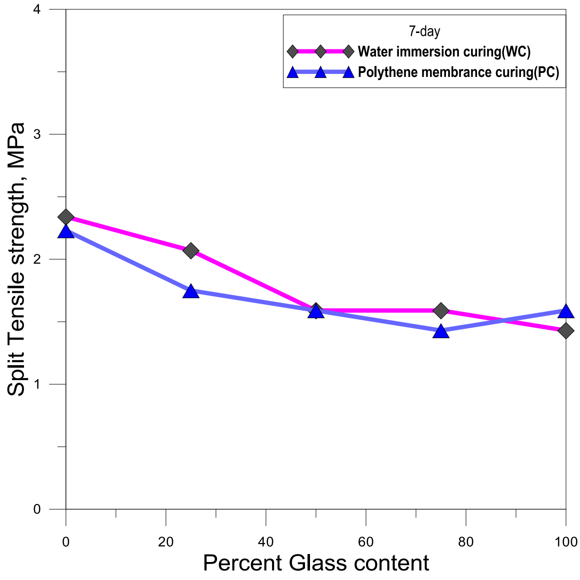

Figure 10: Comparison of split tensile strength against glass content for 7-day and 14-day water and polythene curing

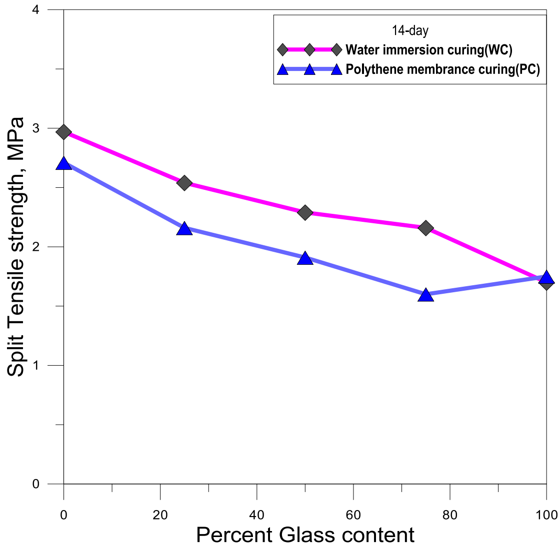

Figure 11: Comparison of split tensile strength against glass content for 7-day and 14-day water and polythene curing

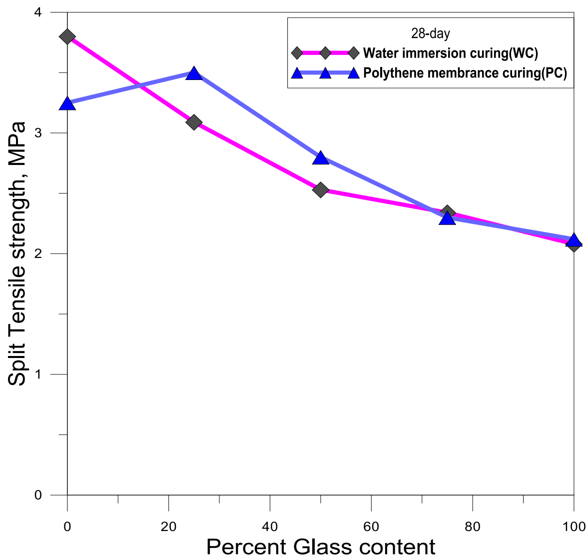

Figure 12: Comparison of split tensile strength against glass content for 28-day water and polythene curing

IV. Conclusions

Based on the experimental test results obtained in this research, the following conclusions can be drawn:

i. The control concrete specimens and concrete specimens containing crushed waste glass cured in water and those cured by polythene sheet covering showed similarity in their compressive and split tensile strength development.

ii. The use of curing by complete immersion in water is more effective. The concrete cured by immersion in water met the minimum required strength of 20 MPa at 28-day curing period. This is attributed to the sufficient moisture available for good cement hydration reaction resulting in improvement of the concrete pore structure.

iii. The use of polythene sheet covering as curing method gives a lower compressive and split tensile strength. This may be as a result of early moisture movement from the concrete resulting in drying out of the concrete.

iv. The drying out of the concrete resulted in the slowing down or stopping of the hydration process which will significantly affect the strength development of the concrete.

v. However, the highest compressive and split tensile strength was obtained for concrete containing crushed waste glass at 25% replacement cured by water immersion, at 28-day curing period.

vi. Generally, the study show that curing by complete immersion in water is the more effective method of curing for concrete. This is necessary to achieve a better performance hardened concrete.

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