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EFFECT OF CURING REGIMES ON THE ENGINEERING PROPERTIES OF HYBRID FIBER REINFORCED CONCRETE

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ABSTRACT

In this study, the effects of curing regimes on the engineering properties of hybrid fiber reinforced concrete were investigated experimentally. Three type conventional concrete mixtures with no fiber, fiber and hybrid fiber having almost same slump value were designed. Later, specimens produced from these concrete mixtures were exposed to different curing conditions namely standard 23±2 °C water, sealed and air curing regimes. After 7 and 28 curing days, the mechanical tests were carried out to determine compressive, splitting tensile, flexural strength and ultrasonic pulse velocity. Also, the flexural performance of concrete specimens was determined by four-point bending test. Finally, the concrete specimens cured in water had the best mechanical properties and energy absorption capacity while those of concrete specimens cured in air were the worst. The specimens cured in sealed condition had similar mechanical properties compared to the specimens cured in water. Moreover, the deflection-hardening response was observed in all fiber reinforced concrete specimens.

Keywords: Macro Steel Fiber, Micro Steel Fiber, Curing Conditions, Deflection-hardening response, Engineering properties

1. INTRODUCTION

Concrete was the most widely used as building material today due to its desired shape, economical and easy to find. Traditional concrete is produced by mixing aggregate, cement and water. The compressive strength of the concrete was increased considerably as results of many studies carried out by researchers and it became a material that benefited from this feature. As concrete strength increases, axial deformation capacities increase. After the peak, the stress drops sudden and a brittle fracture was observed because of its high compressive strength. For this purpose, fiber reinforcement was used in concrete to eliminate these problems that occur in concrete, and thus, increase in the tensile strength and ductility of the concrete was provided.

The first studies on fiber reinforced concrete were performed in 1950 to understand the engineering properties of fiber reinforced concrete [1]. Fiber reinforced concrete was defined as concrete containing randomly directed fibers [2]. In today's construction industry, fiber-reinforced concrete was used in many applications such as industrial slabs, bridges, aircraft runways and precast elements. To convert the brittle behavior of concrete, the fiber addition into the concrete mixes were probable. It improves the tensile strength of concrete and control the cracking. Fibers bridged the cracks and therefore, the propagation of localized crack postpones [3]. For these aims, fibers such as steel fibers, polypropylene, polyester, glass, polyethylene, polyvinyl alcohol, etc. were used. Steel fibers have greater Young’s modulus of elasticity and higher strength in comparison to other fibers. The steel fibers added into concrete mixes improved the mechanical properties and flexural toughness. Post-crack load carrying capacity also developed. Fiber-reinforced concrete, which consists of a mixture of multiple discontinuous fiber types and conventional concrete matrix, was defined hybrid fiber-reinforced concrete [4]. The view of hybrid fiber in concrete mixture was first proposed by Rossi et al. [5]. The combination of micro fibers that controls the initiation and spread of micro-cracks and macro fibers that control macro-cracks in hybrid fiber-reinforced concrete provide important advantages in terms of mechanical properties [6]. The effect of steel fibers belongs to not only their property like geometry, distribution and concentration but also the properties of concrete just as paste ratio, maximum aggregate grain size, etc.

Suitable curing of concrete after casting was significance to provide required engineering properties. Besides, appropriate curing plays an important role in success optimum performance/full potential from a given concrete mixture [7]. The study carried out by Bentz et al. [8] shows that curing conditions have important effect on the rate of hydration of cement. In the study conducted by Yazicioglu et al. [9], the engineering properties of self-compacting concrete (SCC) under different curing conditions were investigated experimentally. Portland cement concrete and two types of SCC i.e., SCC with fly ash and SCC with silica fume, concrete specimens are prepared and cured in three different curing conditions, namely water, sealed and air cured for the different periods of 3, 7, 14 and 28 days. The conclusions indicated that water cured specimens always give the highest values followed by those cured as sealed and in air irrespective of type and age of concrete.

The essential aim of this study is to search the influence of different curing conditions on the engineering properties of hybrid and single containing fiber concrete in comparison with normal concrete by using determined test methods.

2. MATERIALS AND METHODS

2.1. Materials and mixture proportions

For this study, CEM I 42.5 Type I Portland cement was used for all concrete mixtures and the chemical composition and physical properties of Portland cement was indicated in Table 1. Two different groups of aggregates were used. In the first one, the aggregate sizes were in the range of 0-5 mm and its specific gravity and water absorption values were 2.53 and 1.90%, respectively. The aggregate sizes of the second were 5 to 15 mm. The specific gravity of that group was 2.62 and water absorption was 0.50%. The grading of the total aggregate was showed in Table 2 and as can be seen the maximum aggregate size was 16 mm. The specific gravity of plasticizer based polymer used in all concrete mixtures was 1.09. Moreover, to develop the tensile strength of concrete mixtures, macro and micro steel fibers were added to concrete mixtures as single and hybrid. The geometry of macro (Dramix 65/60) and micro (OL 13/.16) steel fibers showed in Figure 1. The properties of their geometry and mechanical were shown in Table 3. Three concrete types were selected, namely control concrete without fiber, concrete containing only macro fiber of 1% (MAC1.00) and the concrete containing 0.80% macro and 0.20% micro fiber named hybrid fiber (MAC0.80). Details of the concrete mix compositions and properties of fresh concretes were showed in Table 4.

Table 1. Chemical composition of portland cement used in concretes (%)

Composition	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	Na_2O	Specific gravity (g/cm^3)
PC	19.41	5.58	3.67	58.85	2.12	3.16	0.69	0.61	3.15

Table 2. The grading of the total aggregate

Sieve size (mm)	16	8	4	2	1	0.5	0.25	0.125
Aggregate (% passing)	100.00	59.80	39.19	23.74	13.34	9.40	6.11	3.80

(a) (b)

Figure 1. Shape of macro and micro fibers used in the mixtures

Table 3. Properties of the macro and micro fibers

Fiber	**Diameter (mm)**	**Length (mm)**	**Aspect Ratio**	**Tensile Strength (MPa)**	**Elastic Modulus (GPa)**	**Density (kg/m^3)**
Macro (Dramix 65/60)	0.92	60	65	2300	210	7850
Micro (OL 13/.16)	0.15	13	87	3000	200	7200

Table 4. Concrete Mixes (kg/m^3)

Mixture Name	**Cement**	**Water**	**Steel Fiber**		**Aggregate**		**Normal Plasticizer**	**Slump (mm)**
			Macro	**Micro**	**0-5 mm**	**5-15 mm**		
CONTROL	350	200	0	0	1025	684	8	12
MAC1.00	350	200	78.5	0	1004	670	12	12
MAC0.80	350	200	62.8	14.4	1001	668	12	9

2.2. Specimen preparation and curing of specimens

All concrete specimens were cast on a vibrating table to provide optimum compaction. The compressive strength and ultrasonic pulse velocity of the concrete mixtures were evaluated by using three cube specimens with the dimensions of 100x100x100 mm according to ASTM C39 [10] and ASTM C597-16 [11], respectively. To specify splitting tensile strength as per ASTM C496 [12], cylinder specimens with the dimensions of Ø100x200 mm were used. The flexural tensile strength of the concrete mixtures were evaluated by applying four point bending test by using 80x100x300 mm prismatic specimens according to ASTM C1609 [13] . In the following day of casting, the concrete specimens were de-moulded and located in three different curing conditions, namely standard 23±2 °C water, sealed and air cured for the periods of 7 and 28 days. At the end of each curing period, a total of three specimens from all concrete mixture were tested for each engineering property. All tests during this study were performed at 7 and 28 days for all curing conditions. The performance of MAC1.00 and MAC0.80, have been examined with respect to relevant properties of control concrete.

3. RESULTS AND DISCUSSIONS

3.1. Compressive Strength

The results obtained from compressive strength tests for control concrete, MAC1.00 and MAC0.80 for all concrete ages and curing conditions were showed in Figure 2-4, respectively. It can be seen from these figures that at 7 and 28 curing days, the compressive strength of the MAC1.00 mixture containing macro steel fiber showed little reduction for all curing conditions compared to the control concrete specimens. Moreover, in the concrete mixture of, the adding of micro steel fibers to MAC0.80 mixture had a positive effect on compressive strength. It was also displayed that the highest compressive strength values were derived from standard water curing followed by the sealed and air curing regimes irrespective of the concrete types. But the compressive strength values of mixtures exposed to sealed curing conditions were close to that of the mixtures exposed to standard curing. Moreover, the effect of curing regimes on the compressive strength of the mixtures was seen in general at 28 days while the compressive strength values of the mixtures at 7 days were close to other. Based on the results of the 28-days the control mixture compressive strength for water curing, the compressive strength of the mixture with single fiber decreased with 6.7% and that of the hybrid fiber reinforced mixture increased with 6% for water curing condition. Similar results were found by Pierre [14] that the compressive strength of the concrete of the steel fiber-reinforced was studies on changes approximate by ±25%. In the literature, it was observed in the studies on the hybrid fiber reinforced concretes that the micro fibers were more effective in preventing the formation and spreading of micro cracks in the concrete specimens exposed to the load, thus, improving the compressive strength of the concrete [15].

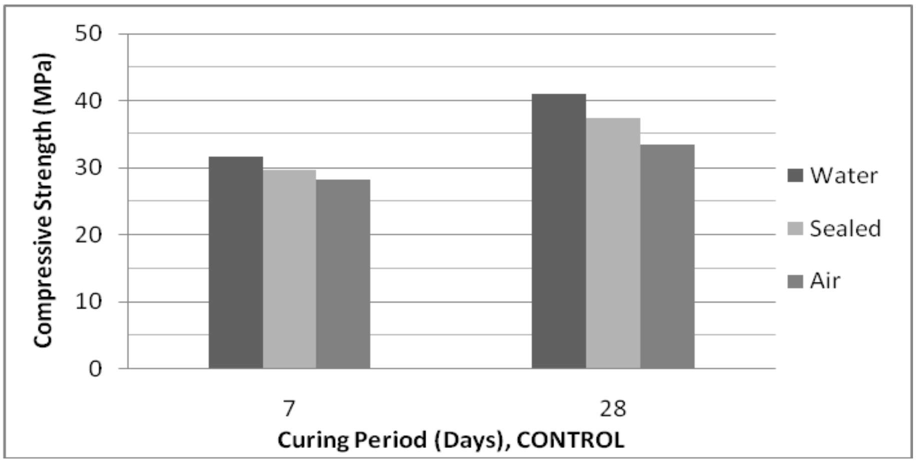


Figure 2. Compressive strength results for CONTROL

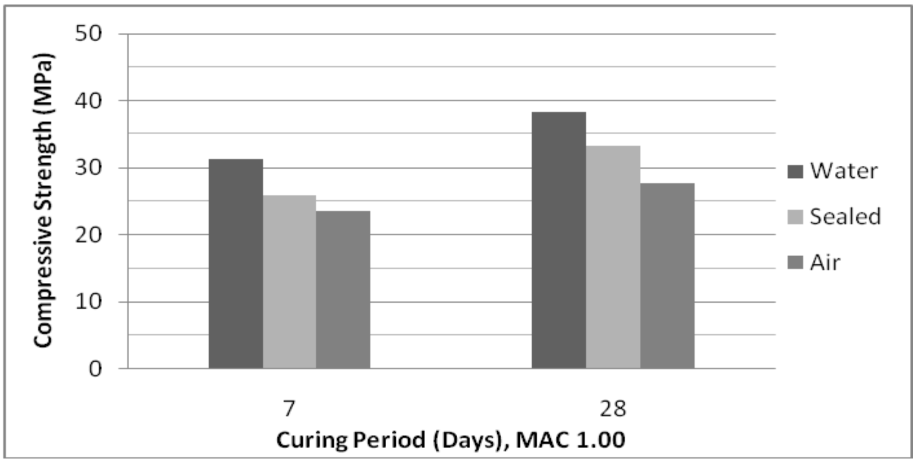


Figure 3. Compressive strength results for MAC1.00

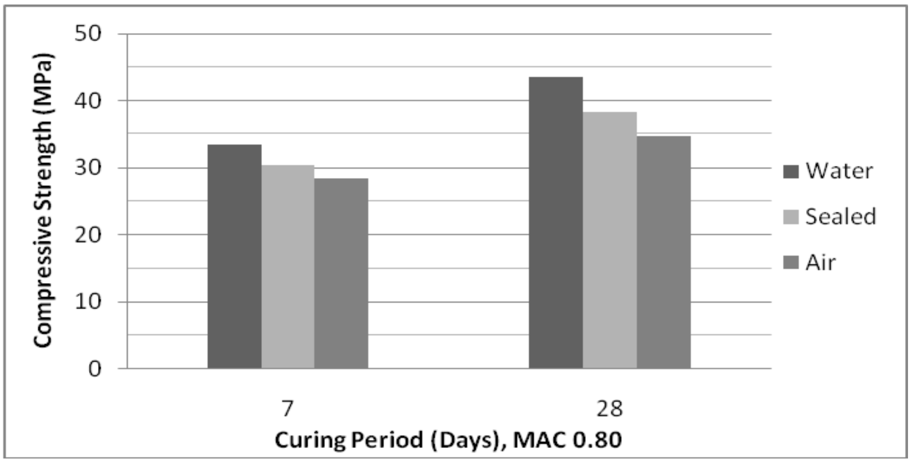


Figure 4. Compressive strength results for MAC0.80

3.2. Splitting tensile strength

The splitting tensile strength results for the three types of concrete, control concrete, MAC1.00 and MAC0.80, for three different curing regimes at the 7 and 28 days curing periods were given in Figure 5-7, respectively. It was showed in these figures that the improvement of splitting tensile strengths of MAC1.00 was the highest followed MAC0.80 and control concrete. Based on the results of the 28-days the control mixture splitting tensile strength for water curing, the splitting tensile strength of the mixture with single fiber increased with 64% and that of the hybrid fiber reinforced mixture increased with 28% for water curing condition. Similar results were found by Mazaheripour et al. [16] that fiber reinforcement to concrete increased the splitting tensile strength of concrete. When the effect of curing methods on the splitting tensile strength of concretes were investigated, it was seen that the highest values were obtained from water cured specimens followed by sealed and air cured specimens, regardless of concrete type.

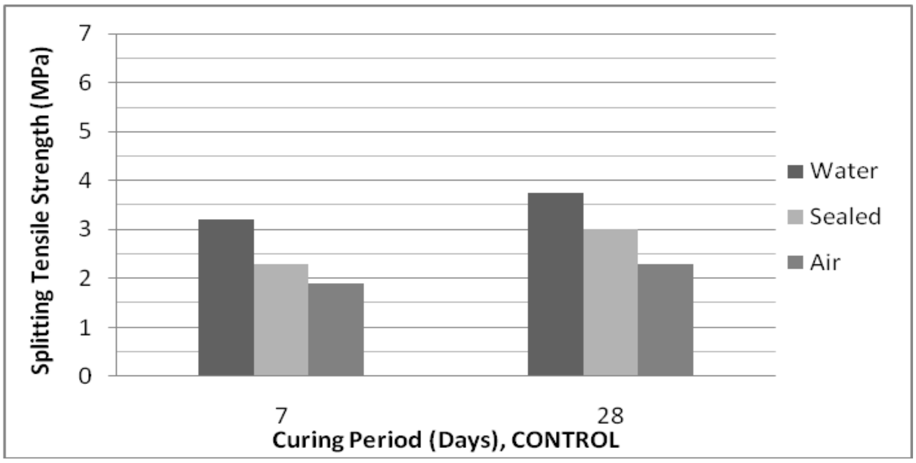


Figure 5. Splitting tensile strength results for CONTROL

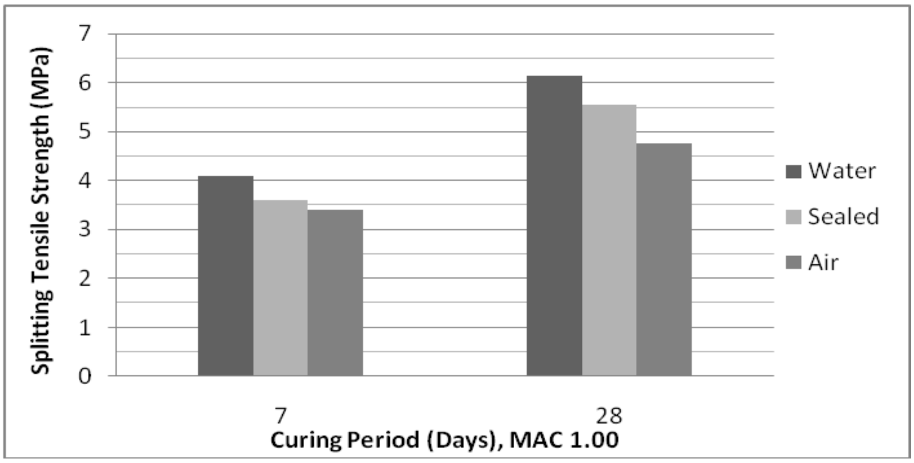


Figure 6. Splitting tensile strength results for MAC1.00

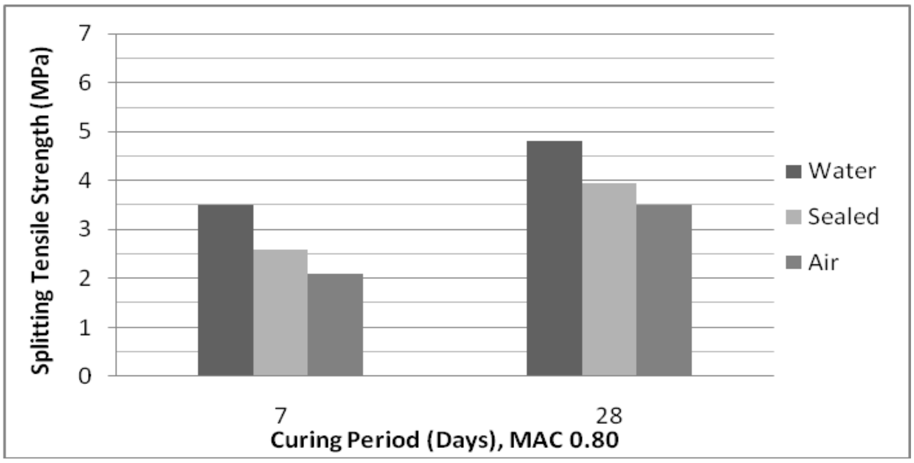


Figure 7. Splitting tensile strength results for MAC0.80

3.3. Flexural Performance

3.3.1. Flexural tensile strength and Energy Absorption Capacity

Figure 8-10 presents the 7 and 28 days flexural tensile strength results for the control concrete, MAC1.00 and MAC0.80 for three different curing regimes, respectively. It was showed in these figures that the improvement of flexural tensile strengths of MAC1.00 was the highest followed MAC0.80 and control concrete. It was also displayed that the highest flexural tensile strength values were derived from water cured specimens followed by the sealed and air cured specimens irrespective of the concrete types. Based on the results of the 28-days the control mixture flexural tensile strength for water curing, the flexural tensile strength of the mixture with single fiber increased with 59% and that of the hybrid fiber reinforced mixture increased with 26% for water curing condition. When micro steel fiber was added to the concrete mixture, the flexural strength of the mixture decreased due to decreasing of macro steel fiber ratio. Because the macro steel fibers bridged the macro cracks but there were insufficient macro fibers due to the replacement of micro steel fibers by macro steel fibers. Therefore, the micro steel fibers get inadequate to enhance the flexural tensile strength. The similar result was also found by Turk et al. [17].

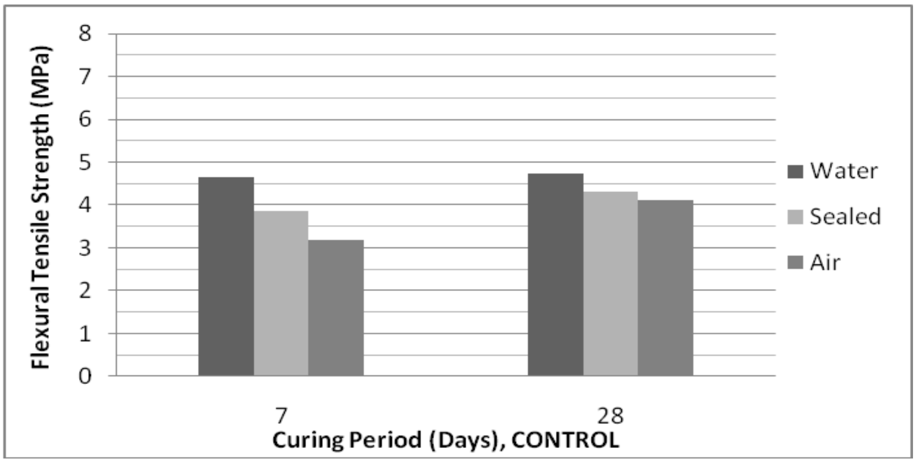


Figure 8. Flexural tensile strength results for CONTROL

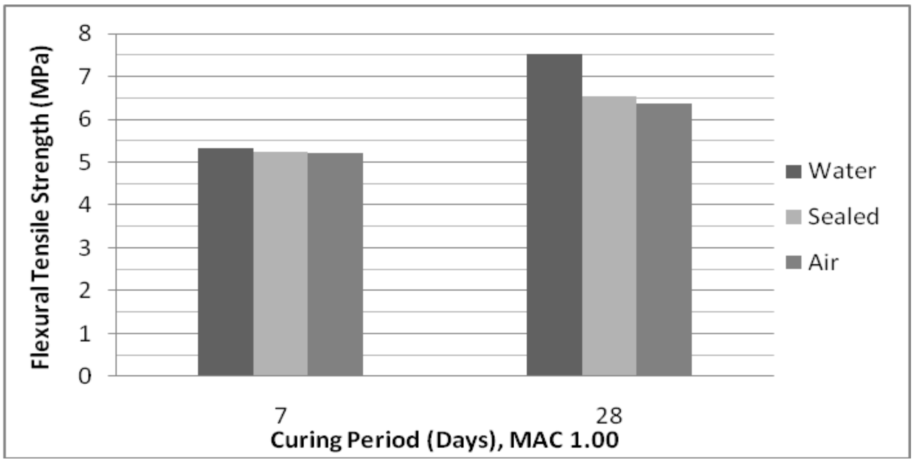


Figure 9. Flexural tensile strength results for MAC1.00

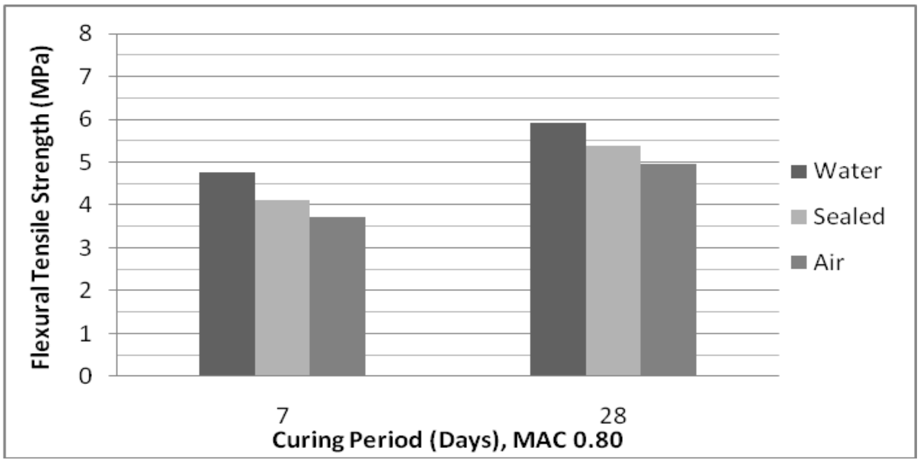


Figure 10. Flexural tensile strength results for MAC0.80

The energy absorption capacity results for three types of control concrete, MAC1.00 and MAC0.80, for three different curing regimes at the 7 and 28 days curing periods were showed in Figure 11-13, respectively. It was seen in these figures that the values of energy absorption capacity of MAC1.00 were the highest followed MAC0.80 and control concrete. For water curing, compared to the results of the 28-days the control mixture energy absorption capacity with 1163 N.mm, the concrete with the single fiber extremely increased with 20238 N.mm and that of the energy absorption capacity with the hybrid fiber increased with 16066 N.mm. The reason for this was that the fibers generate a mechanism with higher energy absorption capacity by preventing crack initiation and growth with effective bridging [18].

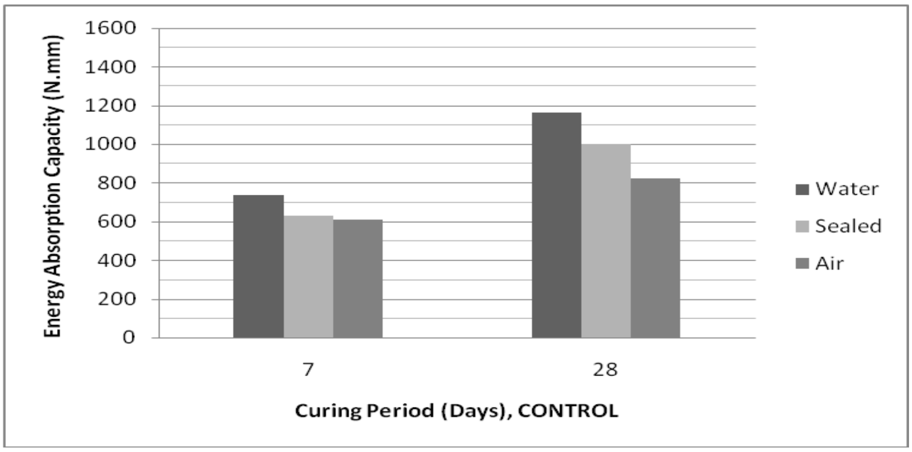


Figure 11. Energy absorption capacity results for CONTROL

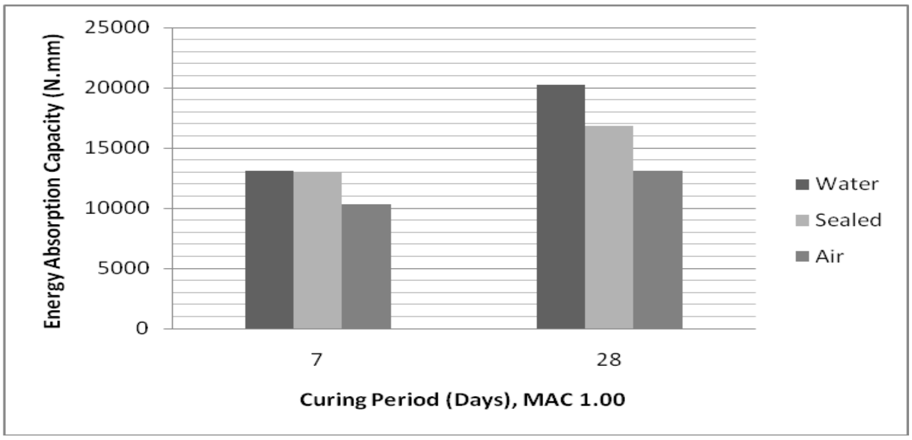


Figure 12. Energy absorption capacity results for MAC1.00

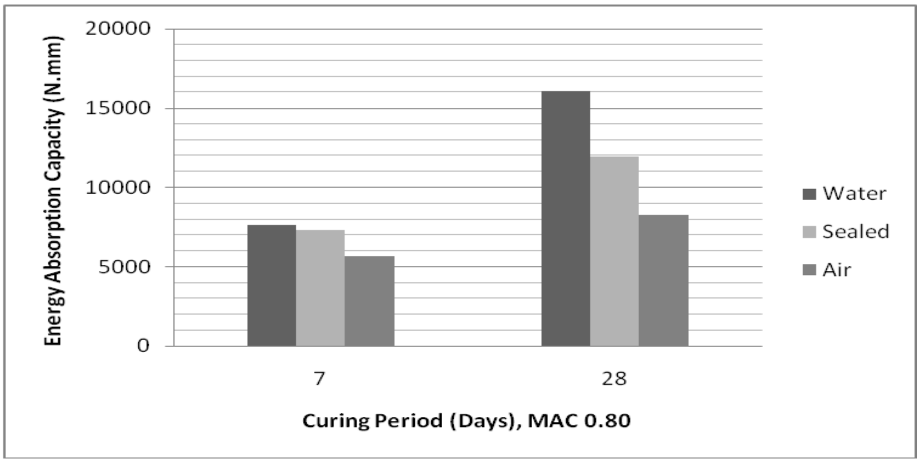
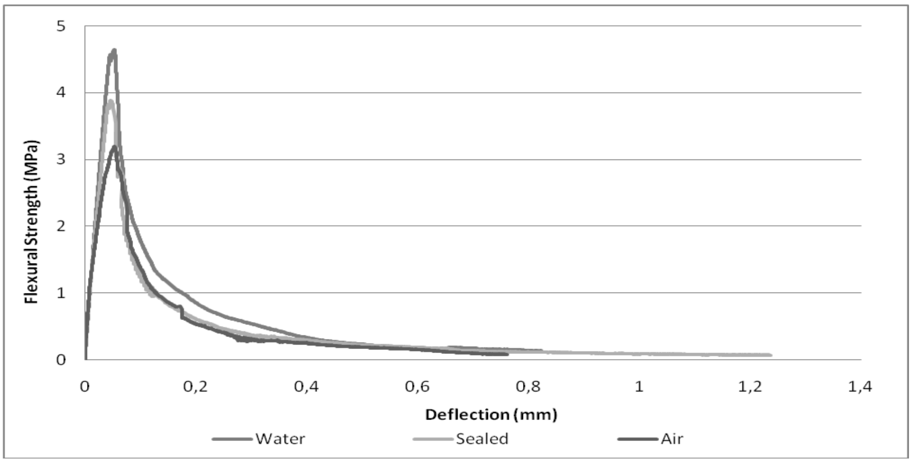


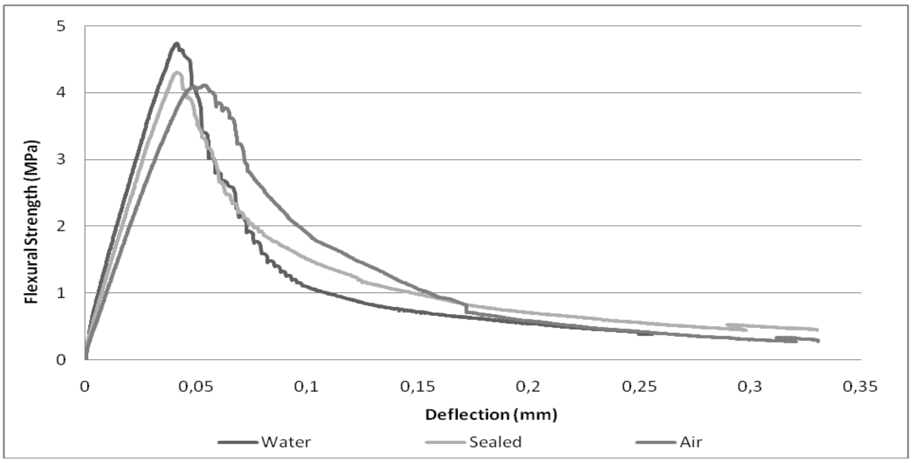
Figure 13. Energy absorption capacity results for MAC0.80

3.3.2. Load-deflection curves

The flexural stress-mid span deflection curves for the beam specimens of control concrete, MAC 1.00 and MAC 0.80 for three different curing methods at the 7 and 28 days curing periods were showed in Figure 14-16. The peak stress values in figures represented the flexural strength values of the concrete specimens and the mid-span deflection capacity was the maximum deflection related to maximum flexural strength. As seen in Fig. 15 and 16, the deflection-hardening response was observed in all fiber reinforced concrete specimens. The existence of steel fibers in the mixtures converted the brittle behavior of concrete to ductile behavior (See fig. 14-16). Moreover, the results derived from four-point bending tests proved that the addition of hybrid fiber to concrete mixtures was usually adequate to provide the deflection-hardening behavior. Turk et al. [17] and Caggiano et al. [19] also found similar results.

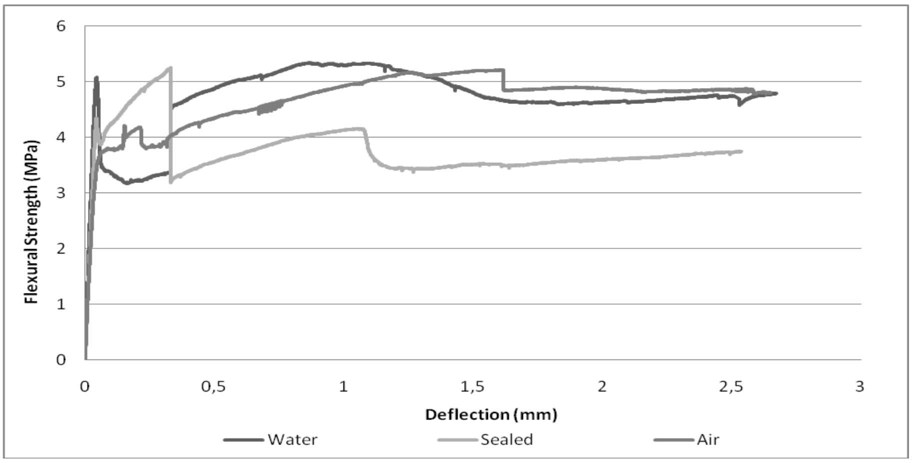


(a)

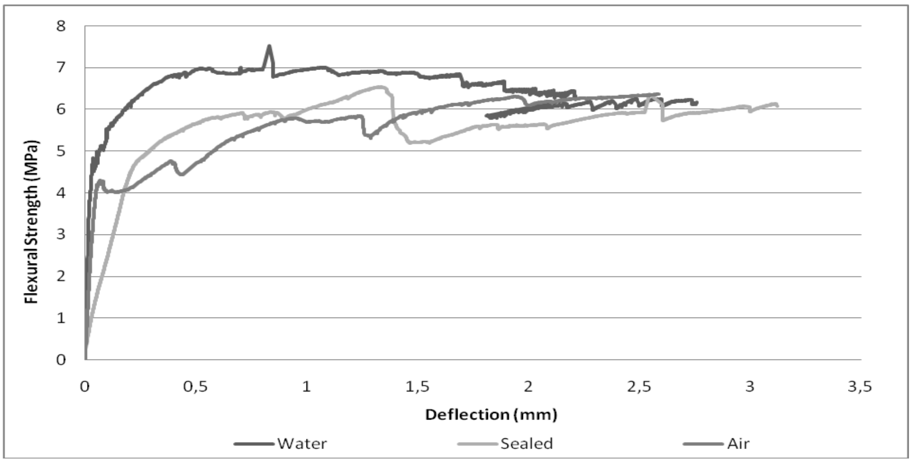


(b)

Figure 14. Flexural stress-deflection curves of CONTROL specimens at (a) 7 days and (b) 28 days

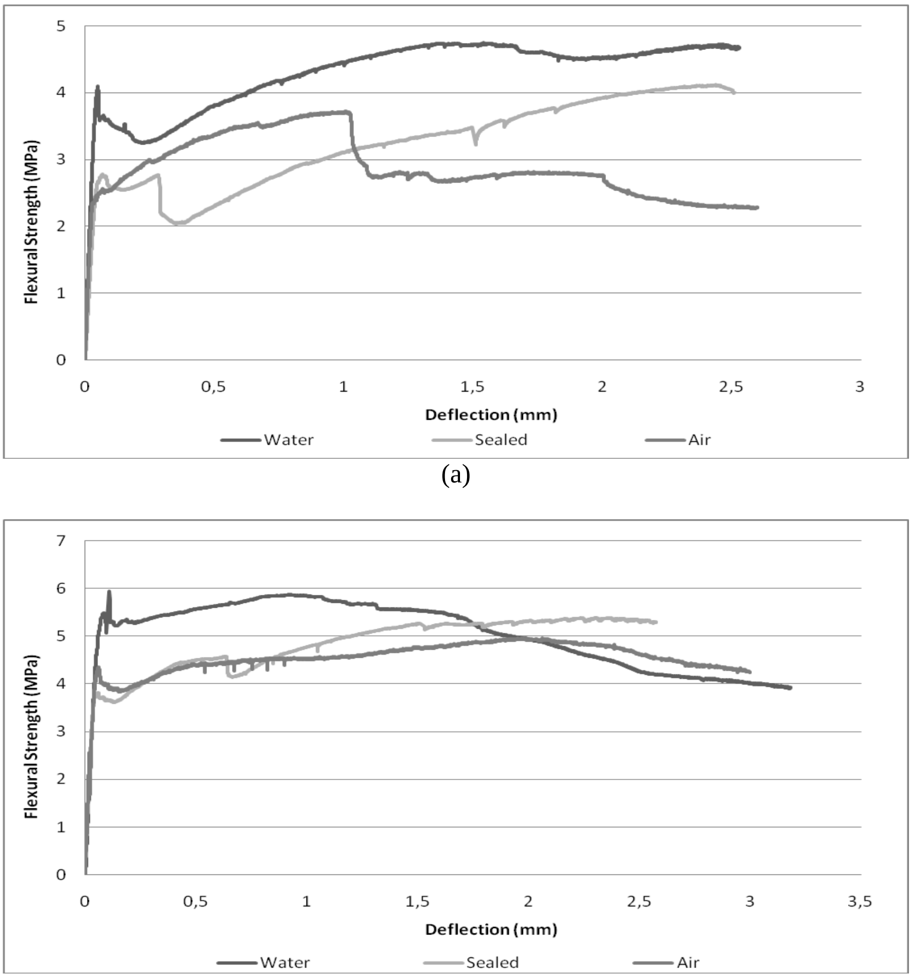


(a)



(b)

Figure 15. Flexural stress-deflection curves of MAC1.00 specimens at (a) 7 days and (b) 28 days

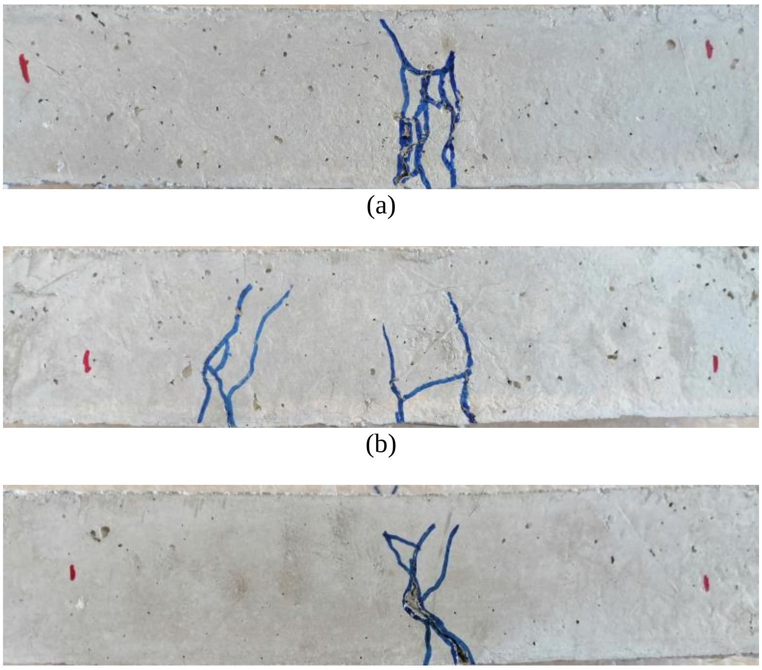


(a)

(b)

Figure 16. Flexural stress-deflection curves of MAC0.80 specimens at (a) 7 days and (b) 28 days

Crack control was crucial for the mechanical and durability performance of concrete. The cracks occasioned by overloaded concrete element caused important failure. In this regard, the inclusion of fiber was significant. The usage of steel fibers ensured substantial resistance against crack initiation and propagation [20]. As seen in Fig. 17, in the midpoint of the beam specimens, the pattern of multiple cracks was apparent in the mixture MAC 0.80 (a) water, (b) sealed and (c) air curing conditions.


(a)

(b)

(c)

Figure 17. Images of MAC 0.80 mixtures after four-point bending test at 28 days (a) Water, (b) Sealed, (c) Air

3.4. Ultrasonic pulse velocity (UPV)

Figure 18-20 show the UPV test results for control concrete, MAC1.00 and MAC0.80 concretes, respectively, at 7 and 28 days for all curing regimes. The highest UPV values were attained from the MAC1.00 followed by control concrete and MAC 0.80 concretes. Water cured concrete specimens for all concrete types gave the highest values then followed by sealed and air cured concrete specimens also indicated the role of moisture degree on the hydration development [9,21].

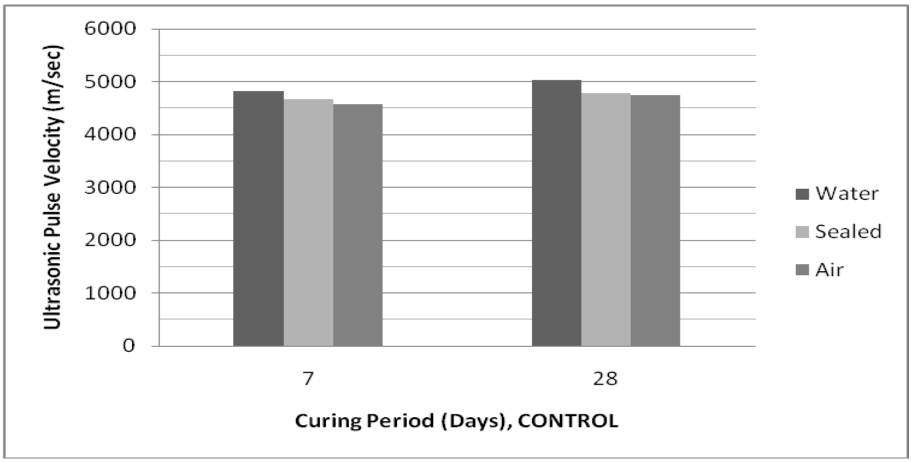


Figure 18. Ultrasonic pulse velocity results for CONTROL

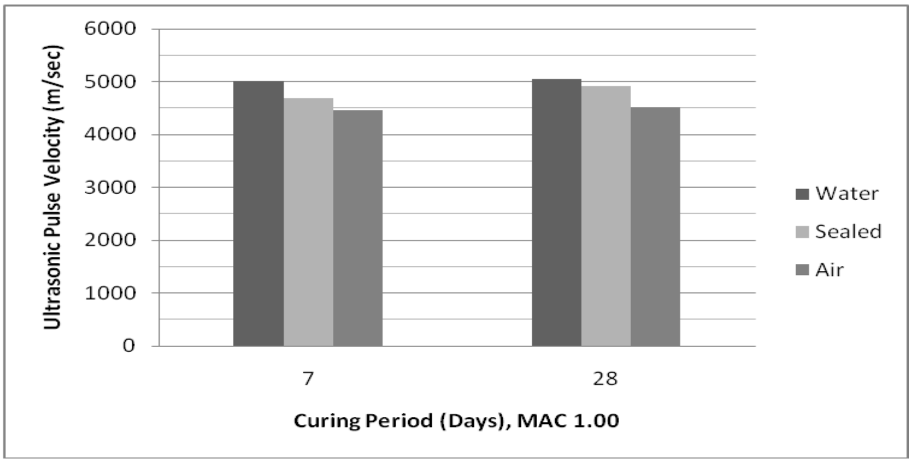


Figure 19. Ultrasonic pulse velocity results for MAC1.00

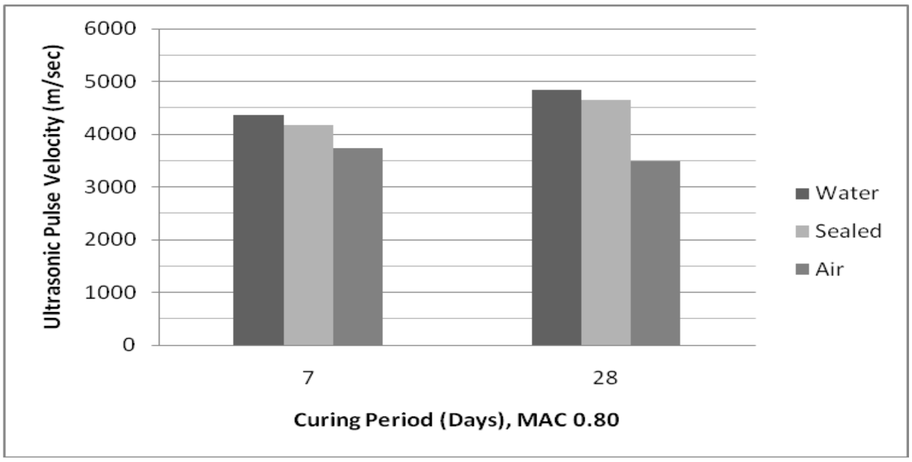


Figure 20. Ultrasonic pulse velocity results for MAC0.80

3.5. Comparison of tensile and compressive strength

The flexural tensile and compressive strength results of control, MAC1.00 and MAC0.80 concretes were showed in Figure 21, on the basic of the curing method applied. It is showed in this figure that as the concrete compressive strength increased, the flexural tensile strength also increased. In general, the correlation between the values of compressive strength and flexural tensile strength were well with R^2 values of over 0.90. The MAC1.00 obtained the highest values while the control concrete and MAC0.80 concretes were near.

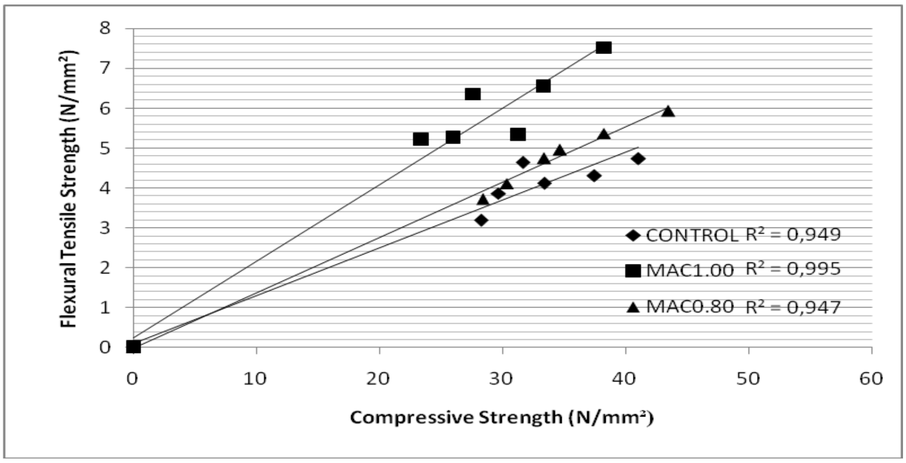


Figure 21. Comparison of compressive and flexural strength of concrete

4. CONCLUSIONS

Based on the experimental study carried out, the following conclusions can be drawn: It was also displayed that the highest values of engineering properties for all curing ages were obtained from standard water curing followed by the sealed and air curing conditions irrespective of the concrete types. Also, the engineering properties values of concrete mixtures exposed to sealed curing conditions were close to that of the mixtures exposed to standard curing. Hybrid fiber reinforced concrete mixtures had higher the compressive strength, splitting tensile strength, flexural tensile strength and energy absorption capacity for all curing conditions at 7 and 28-day compared to control concrete. Concrete mixtures with only macro reinforced fiber had highest the values of splitting tensile strength, flexural tensile strength, energy absorption capacity and ultrasonic pulse velocity while the compressive strength of the mixtures with hybrid fiber was highest in all concrete mixtures. Moreover, deflection-hardening response and multiple cracks pattern was observed in all fiber reinforced concrete specimens under all curing conditions.

RECOMMENDATIONS

In hybrid fiber reinforced conventional concretes, the dosage of the plasticizer can be reduced by using super plasticizer instead of the normal plasticizer. In this case, it is being thought that the setting retardant effect resulting from the excessive dosage of the normal plasticizer in the concrete will be eliminated.

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