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Difference Curing Conditions on the Engineering Properties of High Strength Lightweight Reinforced Concrete (HSLRC) using Sawdust and Coconut Fiber

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Abstract: This paper studies the effect of different curing conditions using sawdust and coconut fiber as partial fine aggregate replacement in high strength lightweight reinforced concrete (HSLRC). The concrete mix ratio 1:3 was prepared using water-cement ratio of 0.35 with level of 0%, 20%, 35%, 50%, 65% and 80% of sawdust and 3% coconut fiber as reinforcement in air environment (A-series) and water curing (W-series) were evaluated in terms of engineering properties i.e., compressive strength, flexural strength, water absorption ,and density. The test results showed that concrete density and compressive strength values decreased while water absorption increased with the increase in sawdust and coconut fiber percentages. However, the strength obtained at HSLRC-50 has met the minimum specified requirement of 40 N/mm^2 for normal concrete. Thus, the results showed A-series most reliable correlation coefficient (R^2) value between these variable parameters compared to water curing W-series. It can be concluded that the air environment curing affected the relationship between variable parameters for long-term exposure days. Using with and without sawdust and coconut fiber can be used as a construction material with acceptable strength and density properties of concrete mix.

Keywords: Construction material, engineering properties, sawdust, coconut fiber, concrete

1. Introduction

High demand in construction materials including bricks, wood, cement, aggregates, steel, aluminum, cladding, and partitioning materials are increasing in demand due to the rapid growth of construction activities for housing and other building (Zakaria et al.,2015). The density of lightweight concrete typically ranges from 1400 kg/m^3 to 2300 kg/m^3 compared to normal weight concrete of 2400 kg/m^3. The use of high strength lightweight can reduce the cross-sectional areas of structural elements and dead load. However, lightweight concrete becomes more brittle for increasing strength levels. It can be considered as a brittle material. To overcomes the brittleness, the application of normal concrete reinforced with sawdust and coconut fiber provides better properties compared to normal concrete, especially in the

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improvement of tensile strength. The research on aggregate replacement in lightweight concrete has been reported (Olutoge, 2010; Oyedepo et al., 2014 & Hasan et al., 2011). They find out the results on the engineering properties and have highlighted the benefits of inclusions the sawdust and coconut fiber as partial fine aggregate replacement. Yet, the variability in the characteristics of the high strength fiber-reinforced lightweight aggregate concrete has been reported and much more research is still needed (Kayali et al.,2003).

Sawdust is collected from fine particles of hard and softwoods. This material is produced from cutting wood with a saw into standard useable sizes. Clean sawdust without a large amount of bark has proved to be satisfied. This not introduce a high content of organic material that may upset the reaction of hydration (Neville, 1995). Paramaswam et al. (1978), in their study of sawdust concrete, obtained some encouraging results. Compressive strength values of up to 31 N/mm^2 at 28 days were obtained in a mix proportion of 1:1 that is one part by volume of cement to one part by volume of sawdust. When the mix proportion was changed to 1:2, the 28 days compressive strength reduced to 8.5 N/mm^2 and a mix ratio of 1:3 (cement/sawdust) by volume reduced the 28 days strength value further to only 5 N/mm^2.

As reported by coconut fiber has also tested as filler or reinforcement in different composite materials (Sen & Jagannatha, 2011). Coconut fiber has the potential to be used as reinforcement in concrete and its cheap and durable non-structural element, reduced thermal conductivity of block specimen (Majid, 2010). The additions of the coir also yield a lightweight product and it would resolve the environment and energy concern. Abdullah et al. (2011) reported fracture behavior of composite cement reinforced with coir can be used as reinforcement and substitute of sand. Increasing the content of fiber will increase modulus rupture and compressive strength. The best results are using 9% of the coir. The fracture behavior of high strength composite consists of crack bridging and fiber responsible to resist the crack propagation and improve the strength of the composite.

Therefore, the present study aims to investigate the effect of different curing conditions on the engineering properties of high strength lightweight reinforced concrete (HSLRC) using sawdust and coconut fiber.

2. Experimental Procedure

2.1 Materials

Ordinary Portland Cement (OPC) ASTM Type I and silica fume were used as the binder for mixing mortar complying with specifications in ASTM Standard C150 (1998). Silica fume was used as admixture at a level of 1.5% by cement weight. River sand was sieved to obtain the size range passing through 5.00 mm, which complies with British Standard test sieve (British Standard Institution, 2013). In this study, the specific gravity of the sand was 2.67 used as fine aggregate. Sawdust collected from various hardwoods and softwoods such as Merbau, Nyatoh, Sentang, Meranti and Cengal wood. The majority of the fine particles of sawdust passed through 5.00 mm British Standard test sieve (British Standard Institution, 2013). Before used it, sawdust should be washed and cleaned because of the large amount of bark, which can affect the setting and hydration of cement (Omoniyi et al., 2014; Usaman et al., 2012 & Ganiron, 2015). After that, it was sun-dried, sieved and then kept in the barrel. Coconut fibers were chopped with sharp scissors to maintaining a length from 15mm to 30mm (Hasan et al., 2011). Superplasticizer is a type of water-reducing admixture was incorporated into the mixtures to maintain the workability of mixes.

2.2 Mix Proportions

Mix proportions were done based on volume. The mix ratio 1:3 and water/cement ratio was used 0.35 were constant for all the mixtures. The percentages replacement of fine aggregates by sawdust were 0%, 20%, 35%, 50%, 65%, and 80%. While coconut fiber also used as reinforcement by 3% for all mixes. The control specimen was denoted as CTRL, while the HSLRC-20, HSLRC-35, HSLRC-50, HSLRC-65 and HSLRC-80 were denoted according to the percentages of fine aggregate replacement.

Table 1 – Mix proportions (kg/m^3)

Mix	**Cement** (*kg/m^3*)	**Sand** (*kg/m^3*)	**Water** (*kg/m^3*)	**Silica Fume** (*%*)	**Sawdust** (*%*)	**Coconut Fiber** (*%*)
CTRL	542	1674	195	1.5	0	0
HSLRC-20	542	1289	195	1.5	20	3
HSLRC-35	542	1039	195	1.5	35	3
HSLRC-50	542	837	195	1.5	50	3
HSLRC-65	542	536	195	1.5	65	3
HSLRC-80	542	285	195	1.5	80	3

2.3 Test Methods

Mixing procedure was the following: cement, silica fume, and sand were added first, then mixed for 5 min. Second, sawdust was added and mixed for 3 min. Third, superplasticizer and water were added and mixed for 3 min. Then, coconut fiber was added and mixed for 5 min. The lightweight reinforced concrete specimens were cast in molds size 100mm x 100mm x 100mm and 100mm x 100mm x 500mm and compacted on a vibration table for a few seconds. After demolding at 24h, the specimens were kept in two curing conditions, i.e., air environment curing (A-series) and water curing (W-series). The A-series was placed outside the laboratory and exposed to sun radiations and rains. While W-series was sunk in a tank filled with tap water.

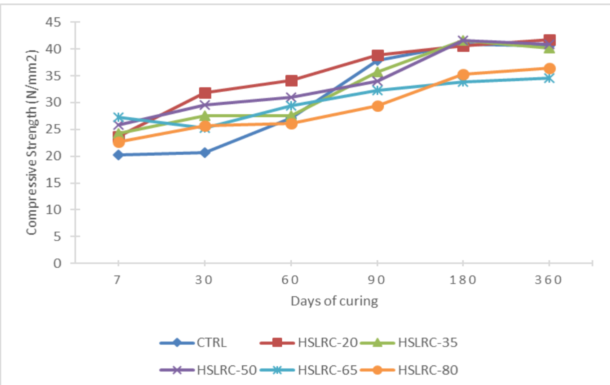
This study includes determination of compressive strength, flexural strength, water absorption and density of in curing period 7, 30, 60, 90, 180 and 360 days. Parameters such as compressive strength, flexural strength, water absorption, Ultra Pulse Velocity (UPV) and density were used to evaluate the engineering properties of the specimens. Compressive strength and flexural strength tests were performed following BS EN 12390-3: 2009 (British Standard Institution, 2009a) and BS EN 12390-5: 2009 (British Standard Institution, 2013b). Water absorption and density of specimens were determined by ASTM C642-97 (ASTM, 2014). The test was done using three cylinders with the dimension 75 mm Ø x 100 mm cored from prisms of each mixture at the period of 7, 30, 60, 90, 180, 360 days. Ultra Pulse Velocity (UPV) test values were taken from three prisms and three cubes from each mix using Portable Ultrasonic Non-Destructive Digital Indicating Tester (PUNDIT) as recommended by the ASTM C597-02 (ASTM, 2003).

3. Results and Discussion

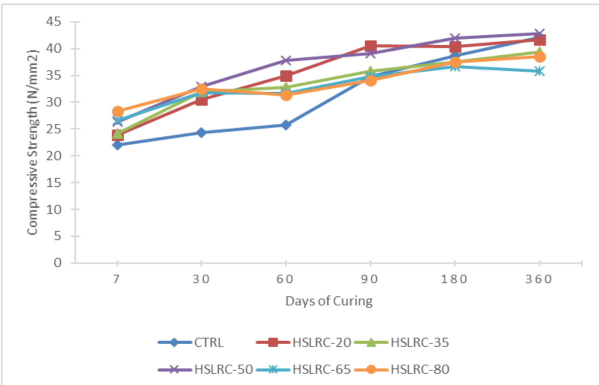
3.1 Compressive Strength

Compressive strength values of specimens were shown in Fig. 1. Three cube specimens were tested per mixture for compressive strength tests at 7, 30, 60, 90, 180 and 360 days subjected to open air curing (A-series) and water curing (W-series). The incorporated sawdust and coconut fiber show similar strength development as the HSLRC where the compressive strength increases overage. However, the sawdust content in lightweight reinforced concrete has greatly affected the compressive strength of the concrete. Among all of the specimens, A-series achieves the highest strength with HSLRC-20, followed by HSLRC-35, HSLRC-50, HSLRC-65, and HSLRC-80 of the level of the sawdust replacement. The results indicate a decreasing trend with increasing sawdust percentages from 20% up to 80% of fine aggregate replacement with curing and concrete age. In Fig. 1(a) values of A-series 41.75 N/mm2, 34.07 N/mm2, 22.73 N/mm2, were obtained for compressive strength with HSLRC-20, HSLRC-35, HSLRC-50 as partial sand replacement. While the result of W-series (Fig. 1(b), compressive strength also decreases with increases of sawdust percentages at HSLRC-20, HSLRC-50, HSLRC-80 in water curing and specimens age. Values of 41.65 N/mm2, 32.96 N/mm2, 28.32 N/mm2 were obtained for compressive strength with 20%, 50% and 80% of sawdust as fine aggregate replacement.

At the HSLRC ages of 30, 60, 90, 180 and 360 days, concrete containing sawdust percentages of fine aggregate replacement, the specimens HSLRC-20 and HSLRC-35 consistently performed equivalent to CTRL. HSLRC-50 had a higher compressive strength as compared to CTRL. Meanwhile, HSLRC-65 and HSLRC-80 had resulted in relatively lower strength of concrete compared to CTRL because of the increase in the air entrainment of the fresh concrete attributed to the difficulties of mixing sawdust and sand in their physical properties (Oyedepo et al., 2014).



(a)



(b)

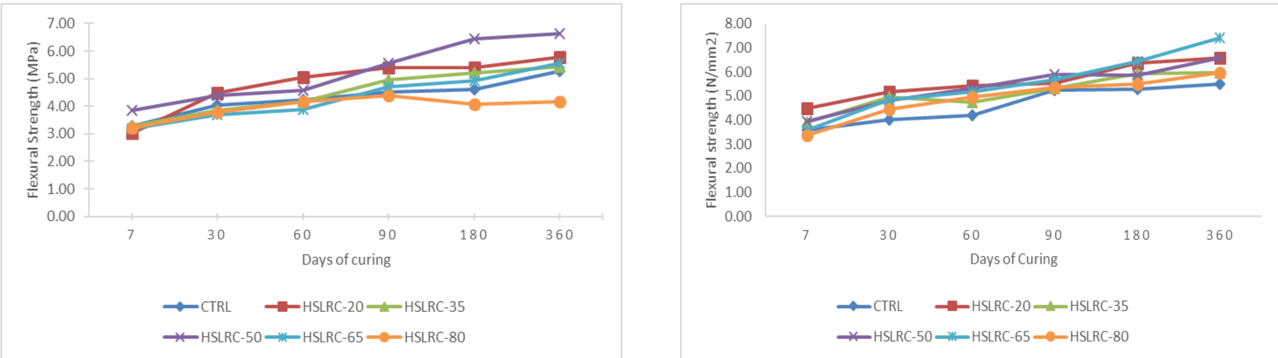
Fig. 1 - Average compressive strength of specimens at various percentages of sawdust as fine aggregate replacement with respect to the days of curing (a) A-series; (b) W-series.

At long term curing age of 360 days, a significant enhancement in compressive strength was exhibited by concrete mixes HSLRC-20 and HSLRC-35 with observed compressive strength of 3% and 1% higher than CTRL. Meanwhile, HSLRC-50 met the equivalent of CTRL concrete in both A-series and W-series. HSLRC-65 and HSLRC-80 still comply with ASTM concrete with compressive strength beyond 40 N/mm2 at the age of 360 days.

The consistent variation exhibited by specimens with 20% to 80% sawdust replacement of fine aggregate at 180 days and 360 days of curing could be attributed to the hydrophilic nature of sawdust (hygroscopic behavior) in specimens. However, the strength obtained at various sawdust inclusions has met the minimum specified requirement of 40 N/mm2 for normal concrete.

3.2 Flexural Strength

The flexural strength for all specimens in the A-series and W-series increased with the curing ages (Fig. 2). After exposing the specimens for 360 days, the flexural strength attained by the HSLRC-80 was lower than CTRL by 21%, whereas HSLRC-20, HSLRC-35, HSLRC-50, and HSLRC-65 achieved higher strength than the CTRL by 25%. In the A-series, HSLRC-20, HSLRC-35, and HSLRC-50 showed enhancement in long term strength. HSLRC content exceeds 50% of sawdust and coconut fiber achieved the highest value. Flexural strength of HSLRC-50 was 41% higher than CTRL specimens, whereas the lower value was recorded at HSLRC-80, 11% lower than the CTRL. The flexural strength of the HSLRC-80 started to saturate after 180 days while the rest was still in an increasing trend. In W-series, the flexural strength of concrete increased with increasing sawdust and coconut fiber content. The HSLRC-65 and HSLRC-80 achieved higher strength than the CTRL. The curing effects of using sawdust and coconut fiber were more apparent in the W-series as the strength started to maintain when the sawdust content increased. However, the low volume of incorporated sawdust and coconut fiber helped in maintaining the higher flexural strength of concrete (Fig. 4). The coconut fiber addressed the changing volume as well as contributed to the higher strength performance. The deleterious aging effects were also responsible for the negative impact on the flexural strength.



(a) **(b)**

Fig. 2 - Average flexural strength against days of curing (a) A-series; (b) W-series.

The optimum 3% of coconut fiber content that contributed to the achievement of the highest flexural strength and compression strength was different, but the general suggested that the low fiber content had its benefits. This could be due to the nature of the testing mechanism. The compressive mechanism deals from more with the hardness of materials and the distribution of stress throughout the whole matrix. At 360 days, most of W-series specimens attained higher flexural strength; the highest was recorded by the HSLRC-65 at 7.42 N/mm2. The specimens seemed to gain benefits from their exposure water concerning the flexural strength test. A contrasting change in the flexural strength of high sawdust content specimens was also observed when the curing day was prolonged. For instance, before the HSLRC-80 was exposed to the air environment, its flexural strength was 21% lower than CTRL but ultimately become 9% higher than CTRL when it's exposed in water. However, the reduction in flexural strength values due to sawdust replacement was much lower than compressive strength. The higher of sawdust replacement, the higher the decrease in flexural strength values. Sawdust is similar to fibers which are effective in enhancing the performance of concrete specimens in terms of compression rather than flexural by achieving greater dimensional stability in a situation where expansions and shrinkages rapidly occur.

3.3 Relationship between Flexural Strength and Compressive Strength

Relationship between flexural strength and compressive strength of mortar was found according to the following law relating flexural strength (f_{cf} in N/mm^2), to compressive strength (f_{cu} in N/mm^2), k and a are coefficients.

$$f_{cu} = kf_{cf}^{a} \qquad (1)$$

An exponential relationship is plotted (Fig. 3) tested specimens up to 360 days in A-series and W-series which the behavior of strength can be interpolated. The high correlation value indicates that flexural strength values have affected the compressive strength linearly in a positive trend. The correlation coefficient (R2) was found to be 0.909 (A-series) and 0.424 (W-series) as evident from the test results. Furthermore, test results showed significant improvement in flexural strength with the increase in sawdust and coconut fiber content. The inclusions of sawdust and coconut fiber increased the crack resistance of concrete which sawdust has similar to fiber properties.

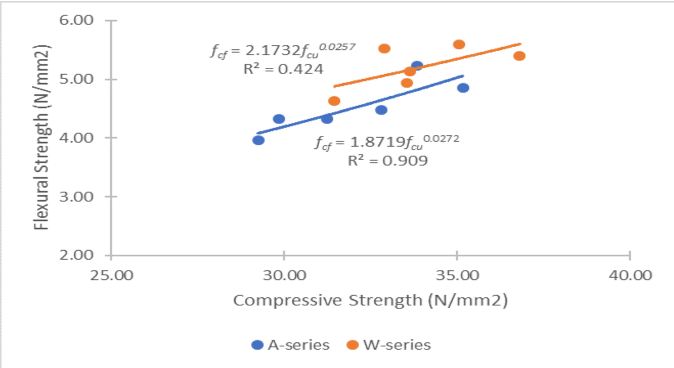
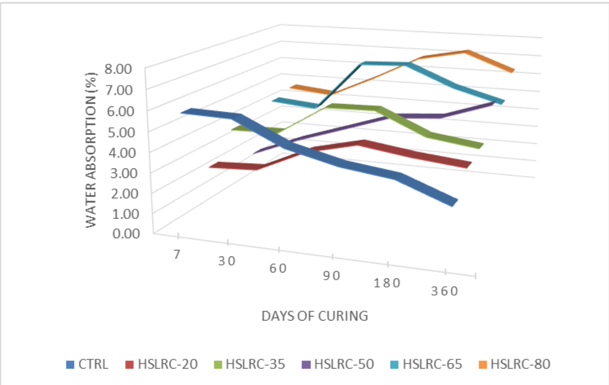


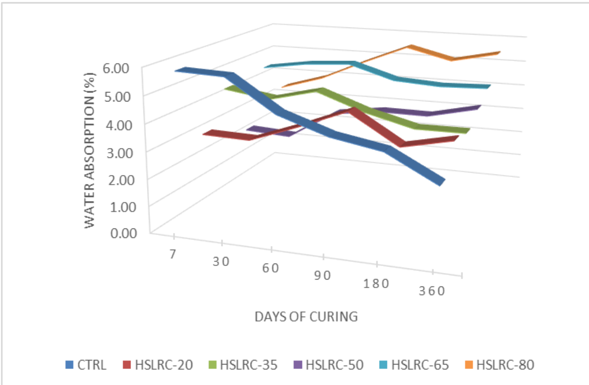
Fig. 3 - Relationship between flexural strength and compressive strength of hardened concrete.

3.4 Water Absorption

Results of water absorption of concrete specimens with various percentages of sawdust are presented in Fig 4. For A-series containing different percentages of sawdust, the water absorption increased with the increase in the percentages of sawdust in concrete. A gradual increase in water absorption of concrete was observed from 3.49 to 6.19% as sawdust content increased from 0% to 80%. Similarly, the normal concrete mixes displayed water absorption of 3.85% when 50% of sawdust was added as a replacement of fine aggregate. The increase in water absorption is related to the porous nature of the fiber (sawdust and coconut fiber). However, these values are still less than the maximum allowable water absorption of 10% for construction materials (Ban and Ramli, 2011).



(a)

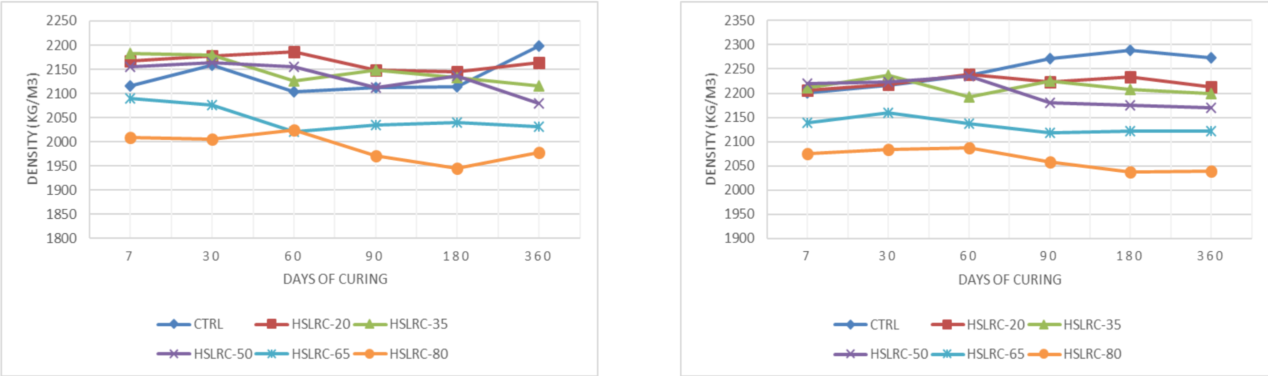


(b)

Fig. 4 - Average water absorption against days of curing (a) A-series; (b) W-series.

3.5 Density

Result of the densities of the specimens with sawdust as fine aggregate replacement shows in Fig. 5. The result showed that the concrete density decreased with the increase in the content of sawdust. For A-series, the density values varied from 1944.2 kg/m3 to 2196.5 kg/m3, showing a 12.98% decrease in hardened concrete density. As far as the density of W-series is concerned, the density of HSLRC-80 was found to be 2037.5 kg/m3 and was 10.36% less than CTRL. The decrease in unit weight is desirable in the context of reducing cross-sectional dimensions of structural elements and dead load. Moreover, reducing dead load is important to decrease the earthquake damage. However, the specimens meet the ACI structural concrete density requirement for both normal concrete (ACI, 2008).



(a) **(b)**

Fig. 5 - Average density against days of curing (a) A-series; (b) W-series.

3.6 Relationship between Compressive Strength and Water Absorption

The relationship between compressive strength and water absorption in air environment curing (A-series) and water curing (W-series) presented in Fig 6. A regression analysis performed on the water absorption and compressive strength data reveals a correlation between water absorption (w, in %) and compressive strength (f_{cu} in N/mm^2) a up to 360 days. A-series has the most reliable R^2 value between these parameters compared to W-series, which is 0.911. It can be concluded that the curing environment plays a role in the relationship between compressive strength and water absorption for long term exposure days. The increasing of sawdust content will increase the water absorption value of the mortar specimens. This comparison analysis proved increasing sawdust content in the concrete mix will increase the water absorption of concrete specimens.

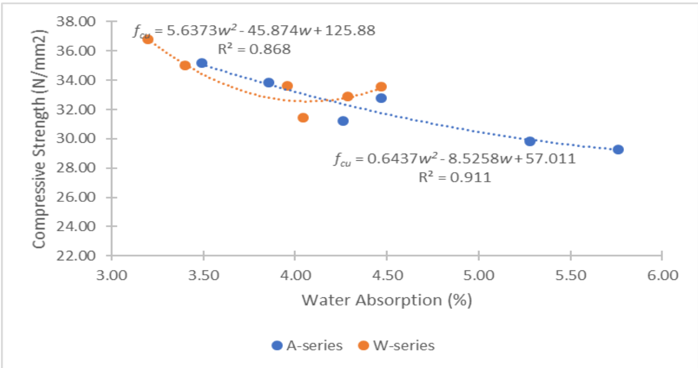


Fig. 6 - Relationship between compressive strength and water absorption

3.7 Ultrasonic Pulse Velocity (UPV)

The ultrasonic pulse velocity (UPV) is based on characteristics and elasticity in the concrete material. The variation of ultrasonic pulse velocity (UPV) with curing time and concrete mix composition showed in Tables 3 and 4. The observed increment trend in the UPV resembles the trend of compressive strength development. Over a prolonged air environment curing and water curing duration of 360 days, there was a slight increment in the UPV with a slight increment at 7 days. By the A-series age of 30 days with sawdust and coconut fiber content of up to 50% had achieved the good quality concrete mix, while the other mix with sawdust and coconut fiber content over 50% were classified as doubtful quality (Table 2).

Table 2 – Classification of quality according to UPV values (Neville, 1995).

Quality of concrete	Value range of UPV (km/s)
Excellent	> 4.5
Good	3.5 – 4.5
Doubtful	3.0 – 3.5
Poor	2.0 – 3.0
Very Poor	< 2.0

Table 3 – Velocities of ultrasonic pulse (A-series)

Mix	7 Days (km/s)	30 Days (km/s)	60 Days (km/s)	90 Days (km/s)	180 Days (km/s)	360 Days (km/s)
CTRL	3.7	3.7	3.9	4.1	4.2	4.2
HSLRC-20	4.0	4.0	4.1	4.0	4.1	4.1
HSLRC-35	4.0	4.1	3.7	3.6	3.8	3.9
HSLRC-50	3.8	3.9	4.0	3.7	3.8	3.7
HSLRC-65	3.5	3.7	3.5	3.5	3.6	3.7
HSLRC-80	3.5	3.5	3.6	3.4	3.3	3.4

Table 4 – Velocities of ultrasonic pulse (W-series)

Mix	7 Days (km/s)	30 Days (km/s)	60 Days (km/s)	90 Days (km/s)	180 Days (km/s)	360 Days (km/s)
CTRL	3.9	4.0	4.1	4.1	4.3	4.3
HSLRC-20	4.0	4.1	4.3	4.2	4.3	4.3
HSLRC-35	4.1	4.2	4.1	4.0	4.2	4.1
HSLRC-50	4.0	4.2	4.1	4.1	4.0	4.1
HSLRC-65	3.7	3.9	3.8	3.8	3.9	3.9
HSLRC-80	3.7	3.7	3.8	3.7	3.8	3.7

By the W-series age of 30 days, the mortar mix exhibited higher values of ultrasonic pulse velocity (UPV) as compared to the air curing even though the strength development was comparatively slower. However, hydration progress up to 360 days by W-series content up to 20% (HSLRC-20) by volume of fine aggregate exhibited similar ultrasonic pulse velocity (UPV) value as compared to CTRL. This can be attributed to the larger amount of sawdust and coconut fiber inclusion in mixes as compared to CTRL.

3.8 Relationship between UPV and Compressive Strength

The general relationship between UPV and compressive strength is shown in Fig. 8 for all concrete specimens up to 360 days. There was a very good exponential relationship between UPV (V, in km/s) and compressive strength (f_{cu} in N/mm^2), since the correlation coefficient, R^2 = 0.679 (A-series), we can say that 67% of the variation in the values of compressive strength is accounted for by the exponential relationship with UPV (Fig. 8). A-series has the most reliable R^2 value between these parameters compared to W-series, which is 0.052. Therefore, it can be concluded that air curing affects the relationship between compressive strength for long term exposure days.

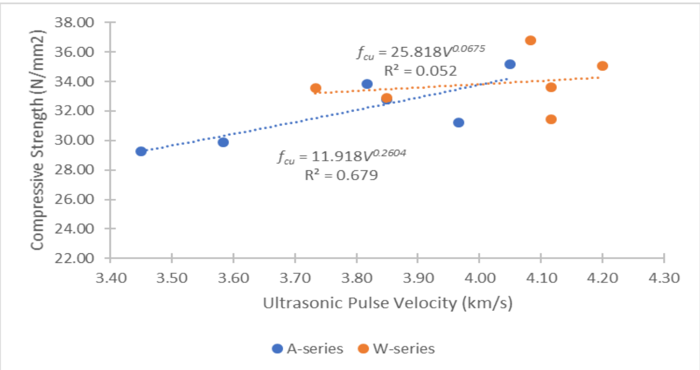


Fig. 8 - Relationship between compressive strength and UPV for air and water curing conditions.

4. Conclusions

Based on the experimental work carried out, the following conclusions were obtained:

a. The compressive strength of A-series and W-series increased in the age of testing while the compressive strength decreased with the increase in percentages of sawdust and coconut fiber in the mixes. The A-series and W-series containing sawdust and coconut fiber showed a compressive strength of more than 42 N/mm2 and 34 N/mm2 respectively at 360 days.

b. In the A-series, except for the HSLRC-80, the rest of the HSLRC specimens achieved high flexural strength throughout the testing period. However, the maximum improvement achieved by HSLRC-50 i.e, 50% of fine aggregate replacement in the W-series in 360 days is approximately 20% higher than CTRL. The inclusions of sawdust and coconut fiber increased the crack resistance of concrete specimens. Sawdust is similar to fibers which are effective in enhancing the performance of concrete specimens in terms of compression rather than flexural by achieving greater dimensional stability in a situation where expansions and shrinkages rapidly occur.
c. The water absorption of A-series and W-series increased with the increase in the percentages of sawdust in concrete. In comparison to CTRL and HSLRC-50 had the maximum increase in water absorption at 6.19% and 3.65% for A-series and W-series respectively. The maximum allowable water absorption for construction materials below 10%.
d. The density of concrete decreased with the increase in the content of sawdust. In comparison to CTRL and percentages of sawdust, the maximum decrease in density for sawdust mix was found to be 12.98% and 10.36% respectively for air curing and water curing. The decrease in unit weight is desirable in the context of reducing cross-sectional dimensions of structural elements and dead load.
e. The ultrasonic pulse velocity (UPV) of A-series and W-series using sawdust and coconut fiber content of 20%, 35%, and 50% had achieved the good quality concrete mix, while the other mix with sawdust and coconut fiber content 65% and 80% were classified as doubtful quality. However, reduction percent of the ultrasonic pulse velocity (UPV) values were less than those of compressive strength. A determination correlation coefficient (R2) of 0.679 indicates A-series has the most reliable R2 value between these parameters compared to W-series, which is 0.052. Therefore, it can be concluded that air curing affects the relationship between compressive strength for long term exposure days.

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