Utilization of Water Hyacinth Ash (*Eichhornia crassipes*) and Fly Ash Reinforced with Water Hyacinth Fibers in the Enhancement of Compressive and Split Tensile Strength of Concrete

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ABSTRACT: Concrete production, a significant contributor to global CO_2 emissions, requires sustainable solutions. One promising strategy is through the use of waste materials in concrete production, which reduces its environmental footprint and addresses the disposal of industrial and agricultural waste. This study explored the partial replacement of cement with water hyacinth ash (WHA) and class F fly ash (FA), reinforced with water hyacinth fibers (WHF), to enhance concrete's split tensile and compressive strengths, and manage waste effectively. The study was conducted in two phases; in the first, mortar cubes were made with varying percentages of WHA and FA, totaling to 30% of the cement being replaced. It was found that using 5% WHA and 25% FA yielded the highest compressive strength following ASTM C109 and ASTM C1437. The second phase assessed the compressive strength, tensile strength, and workability of the concrete mixtures with the best mix ratio from the first phase, reinforced with WHF, following ASTM C39, ASTM C496, and ASTM C143 guidelines. Results demonstrate that incorporating WHA and FA significantly enhanced mortar compressive strength. Furthermore, incorporating an additional 0.1% WHF to concrete achieved the highest tensile strength, reinforcing its structural integrity. The best concrete mixture exhibited superior tensile and compressive strengths compared to the control. This innovative combination improves the mechanical properties of concrete and provides an environmentally friendly solution by utilizing water hyacinth and FA waste. Ultimately, the study concludes that combining WHA, FA, and WHF offers a viable method to produce stronger, more sustainable concrete, addressing structural engineering and environmental challenges.

Key Words: Cement Replacement; Fiber Reinforcement; Water Hyacinth Ash; Fly Ash; Water Hyacinth Fiber

1. INTRODUCTION

The growing demand for construction projects has led to a significant increase in cement production, which has raised environmental concerns, particularly regarding its contribution to climate change (Philippine Statistics Authority, 2023; Imbabi et al., 2012). In the Philippines, the cement production index increased by 1.5% in August 2018 compared to the previous year, reflecting the industry's continuous expansion (Jamora et al., 2020). In response to these environmental challenges, the cement industry is focusing on using alternative materials to reduce reliance on traditional Ordinary Portland Cement (OPC) and improve sustainability (Imbabi et al., 2012).

Water Hyacinth (WH), an invasive plant known for its rapid growth and environmental damage, often creates problems by forming dense clusters that block waterways (Harun et al., 2021). However, due to its mineral content—25% calcium oxide (CaO), 23% silica (SiO_2), and 9% aluminum oxide (Al_2O_3)—WH is being explored as a sustainable resource for construction. Studies have shown that Water Hyacinth Ash (WHA) has better pozzolanic properties compared to cement, improving performance when used in the right proportions (Murugesh & Keziah, 2021).

Similarly, fly ash (FA), a waste product from thermal power plants, is gaining attention due to its availability and potential benefits. Although FA contains heavy metals like arsenic, mercury, and lead, which can pose environmental and health risks if not managed properly (Ebben & Carlson, 2020), its high silica, alumina, and magnetite content make it a suitable option for construction materials. Its pozzolanic properties have been well-documented, with previous studies demonstrating its successful application in concrete (Ahmaruzzaman, 2010).

This study examines the combined use of WHA and FA reinforced with water hyacinth fibers (WHF) as partial replacements for cement in concrete. Several studies were conducted by replacing cement with WHA and FA, separately. Studies by Krishnan & Murugesh (2018) and Yehualaw et al. (2022) showed that WHA improves concrete's compressive strength which peaks at 10% replacement. Similarly, studies by Hodhod (2003) and Abirami et al., (2018), also supported the claim that WHA improves the compressive strength of concrete. In terms of FA, studies by Joshi (2017) and Abushad & Sabri (2017), showed that the workability and durability of concrete improved as the FA content increases. Both studies stated that the optimum replacement of FA is 30%. The incorporation of WHF into concrete mixtures has also been explored, revealing a significant increase in tensile strength—up to 71.4% with 0.5% fiber by volume. Although, this is accompanied by a decrease in compressive strength across various orientations and percentages (Kiptum et al., 2019). Notably, Dewi et al. (2023) reported a 17.6% increase in compressive strength when comparing concrete with 0.5% WHF to conventional concrete without fibers. Based on these findings, the current study proposes that integrating WHA and FA into mortar will yield higher compressive strength compared to traditional mortar, with FA allowing for greater utilization of WHA. Additionally, it is anticipated that this partial cement replacement will improve the workability of the concrete, and that WHF-reinforced concrete will achieve superior compressive and split tensile strengths compared to control samples.

Joshi (2017) reported that partial replacement of cement with fly ash (FA) at levels of 0%, 10%, 20%, and 30% improved the workability and durability of concrete, with 30% identified as the optimum. Similarly, Abushad and Sabri (2017) concluded that 30% FA replacement resulted in the highest compressive strength compared to other replacement levels, with strength declining beyond this point. Based on these findings, this study limits the total replacement of cement using a combination of water hyacinth ash (WHA) and Class-F FA to a maximum of 30%.

The study specifically aims to assess the effectiveness of WHA and Class-F FA reinforced with WHF as partial cement replacements in concrete. It will investigate the effects of varying WHA and FA proportions (0-30% in 5% increments) on the compressive strength of the mortar. Furthermore, the research will evaluate how the mix with the highest compressive strength will affect the workability of the concrete, and identify which treatment group yields the best compressive and tensile strengths.

2. METHODOLOGY

2.1 Research Design

The study investigated the effects of WHA and FA on the workability and compressive strength of mortar, and the effects of WHF on the workability, compressive strength, and split tensile strength of concrete. These were done using various test methods in two distinct phases. (1) Phase One: Mortar Specimens, and (2) Phase Two: Concrete Specimens. The first phase established the best mix ratio by varying the proportions of WHA and FA by 5% increments (by weight) to a total of 30% cement replacement (eg. 5% WHA: 25% FA, 10% WHA: 20% FA, 15% WHA: 15% FA, 20% WHA: 10% FA, and 25% WHA: 5% FA.). This process involved 80 samples of 50x50x50 mm mortar cubes undergoing compressive strength tests (ASTM C109) and slump tests (ASTM C1437). In the second phase, the optimal fiber amount was identified through the addition of WHF varying from 0.1 to 0.3% (by weight). This was performed by utilizing 100 samples of 100x200 mm cylindrical concrete specimens in compressive strength tests (ASTM C39), slump tests (ASTM C143), and split tensile strength tests (ASTM C496). Using the obtained parameters, statistical and graphical analyses were conducted to evaluate the effects of WHA, FA, and WHF on the strength and workability of concrete, as well as to assess the variability and significance of the differences in the results.

2.2 Material Preparation

WH collected from Laguna de Bay in Cardona, Rizal was used and uniformly cut into 2-inch small pieces (Abirami et al., 2018). WhileWHA were obtained through open-burning (Kamal et al., 2023) for 2 hours and was sieved through a 150-micron sieve (Abirami et al., 2018; Das & Singh, 2016; Krishnan et al., 2018). The WHF used was processed in the DOST - Philippine Textile Research Institute (PTRI) and was cut into 2-inch small pieces (Kiptum et al., 2019). Further, the Class-F FA utilized was produced by Pozzolanic Philippines Inc. from Taal, Batangas. Shown in Figure 1 are the pictures of the WHA, FA, and WHF used in the study for reference.

Fig. 1 Photos of WHA (left), FA (middle), and WHF (right)

2.3 Experimental Program

The materials used for both mortar and concrete were weighed according to their proportions. For phase one, a mortar mixer was used for combining the materials. The mortar specimens were cured for 7 and 28 days in a dry place, with five samples per curing period per mix ID.They were then covered with plastic sheets to prevent water evaporation. This condition was maintained until the testing of the specimens. For phase two, a half-bagger concrete mixer was utilized. The concrete specimens were cured for 7 and 28 days (10 samples per curing period per mix ID) in a water tank. The mix proportions for both phases are shown in Table 1 below.

Table 1. Mix Proportion

Material	Phase 1		Phase 2	
	Ratio	Weight (g)	Ratio	Weight (kg)
Cement	1	1000	1	6.83
Water	0.485	485	0.60	4.1
Sand	2.7	2750	3.1	15.89
Gravel			2.3	20.03

A summary of the mix and its corresponding number of samples, percent replacements and additions per phase are listed accordingly in Table 2. The W10F0 and W0F30 were found to be the optimum replacements of WHA and FA, respectively, based on previous studies (Murugesh, 2018; Yehualaw et al., 2022; Joshi, 2017; Abushad & Sabri; 2017). The percentages were prepared using the weight method only. Shown also in the table are the combined number of samples for both curing periods for each mix ID.

Table 2. Summary of Specimens

Mix ID	No. of Samples	% of WHA	% of FA	% Add. of WHF
Phase 1: Mortar Specimens				
W0F0	10	0	0	0
W10F0	10	10	0	0
W0F30	10	0	30	0
W05F25	10	5	25	0
W10F20	10	10	20	0
W15F15	10	15	15	0
W20F10	10	20	10	0
W25F05	10	25	5	0
Phase 2: Cylinder Specimens				
C	20	0	0	0
O	20	5	25	0
WF1	20	5	25	0.1
WF2	20	5	25	0.2
WF3	20	5	25	0.3

Note: W0F0 and C are the control specimens

Water hyacinth fibers were incorporated based on the volume of the concrete. Given that 100 mm × 200 mm cylindrical specimens were used, the fiber content was calculated as 0.1% of the total concrete volume. The corresponding volume was then added to the mix in the form of water hyacinth fibers.

3. RESULTS AND DISCUSSION

3.1 Statistical Analysis of Strength Test Values

A two-way ANOVA was conducted to assess the significance of strength differences between the mixes in both phases.

Table 3. ANOVA Table for Mortar

Variable	F value	p-value
WF	32.860	< 2e-16 ***
Day	20.947	2.23e-05 ***
WF: Day	2.027	0.0651.

Signif. codes: ‘****’ 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Table 4. Duncan Post Hoc Test for WHA and FA Mix

Variable	Diff	p-value
W5F25-W0F0	3.029	0.02277*
W10F20-W0F0	-4.981	0.00041***
W15F15-W0F0	-7.242	1.30E-06***
W20F10-W0F0	-10.642	4.50E-11***
W25F5-W0F0	-12.066	2.20E-12***
W10F0-W0F0	-5.191	0.00031**

Table 3 shows that both the WHA–FA mix and curing days significantly affect mortar compressive strength at a 95% confidence level, while their interaction is moderately significant at 90%. Table 4 shows that W5F25 had significantly higher strength than W0F0 ($p = 0.02277$), while other mixes performed lower, with only W5F25 showing a significant improvement.

Table 5. ANOVA Table for Concrete Compressive

Variable	F value	p-value
Fiber	22.113	6.08e-08 ***
Day	248.051	< 2e-16 ***
Fiber: Day	0.514	0.676

*Signif. codes: ‘****’ 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1*

Table 6. Duncan Post Hoc Test for WHF

Variable	Diff	p-value
WF1-WF0	-2.472	0.0167*
WF2-WF0	-4.950	2.4e-05***
WF3-WF0	-7.575	1.6e-08***
WF2-WF1	-2.478	0.0164*
WF3-WF1	-5.103	1.6e-05***
WF3-WF2	-2.625	0.0115*

Table 5 shows that fiber content and curing days significantly affect compressive strength ($p < 0.001$), while their interaction is not significant ($p = 0.676$), indicating a consistent fiber effect across curing periods. Table 6 shows that all mixes with WHF had lower compressive strength than the control, with greater reductions at higher WHF content, confirmed at 95% confidence.

Table 7. ANOVA Table for the Split Tensile Strength of Concrete

Variable	F value	p-value
Fiber	5.121	0.005249 **
Day	18.54	0.000147 ***
Fiber: Day	0.914	0.445

*Signif. codes: ‘****’ 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1*

Table 8. Duncan Post Hoc Test for WHF

Variable	Diff	p-value
WF1-WF0	0.466	0.558
WF2-WF0	0.190	0.342
WF3-WF0	-0.162	0.006 **
WF2-WF1	0.104	0.151
WF3-WF1	-0.255	0.002 **
WF3-WF2	-0.010	0.045 *

*Signif. codes: ‘****’ 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1*

Table 8. shows that both fiber content and curing days significantly affect the concrete's split tensile strength, while their interaction is not significant. Post hoc comparisons reveal that WF3 consistently had lower tensile strength than WF0, WF1, and WF2, with p-values indicating significant differences. In contrast, no significant differences were observed among WF0, WF1, and WF2.

3.2 Compressive Strength of Mortar Specimen

The average compressive and tensile strengths of statistically validated specimens for each mix combination and for different curing ages are tabulated in Table 3.

Table 9. Summary of Phase 1 Specimens

Mix ID	%WHA	%FA	Comp. Strength (MPa)	
			7-day	28-day
W0F0	0	0	17.09	21.55
W10F0	10	0	11.94	16.32
W0F30	0	30	17.90	19.24
W5F25	5	25	19.41	25.29
W10F20	10	20	12.50	16.18
W15F15	15	15	9.50	14.66
W20F10	20	10	8.43	8.93
W25F5	25	5	6.45	8.07

Table 9 presents the compressive strength results for the mortar specimens, alongside the corresponding percentages of WHA and FA replacement. After the mortar samples were cured for 7 and 28 days, the average compressive strength of the five samples per mortar mixture was determined. The W5F25 mixture exhibited the highest compressive strengths, with values of 19.41 MPa at 7 days and 25.29 MPa at 28 days of curing. Moreover, W5F25 had a higher strength compared to W10F0 and W0F30, which previous studies have claimed to be the optimum replacement for WHA and FA. Results displayed a direct relationship between the addition of FA and the compressive strength of mortar. Previous studies also showed that the mixture with a higher FA content has the optimum compressive strength (Sathawane et al., 2013).

The graphical plot of the compressive strength trends of the mortar samples at both the 7-day and 28-day curing intervals are shown in Figure 2. The W5F25 mix consistently exhibited the highest compressive strength across both time periods. This indicates that W5F25 was the best mix ratio, which was further investigated in subsequent concrete testing to evaluate its tensile strength when reinforced with WHF.

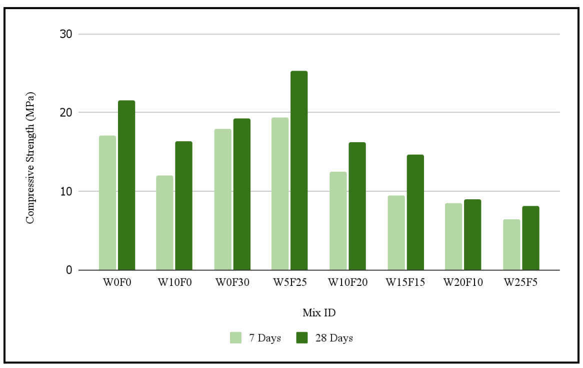

Fig. 2. Compressive Strength of Mortar Specimens

3.3 Compressive and Tensile Strength of Concrete Specimen

Table 10. Summary of Phase 2 Specimens

Mix ID	Fiber %	Comp. Strength (MPa)		Tens. Strength (MPa)	
		7-day	28-day	7-day	28-day
C	0	25.87	33.58	2.30	2.40
O	0	23.47	35.47	2.33	2.72
WF1	0.1	21.74	32.26	2.45	2.80
WF2	0.2	19.66	29.38	2.08	2.62
WF3	0.3	16.22	27.58	1.54	2.42

Table 10 summarizes the compressive strength and tensile strength test results for the concrete samples. After 7 days of curing, the control sample showed a compressive strength of 25.87 MPa, while the concrete with optimal FA and WHA percentages had 23.47 MPa. By the 28-day curing period, the compressive strength of the optimum mixture increased to 35.47 MPa, surpassing the control's 33.58 MPa. In this phase, fibers were added, and an increase in fiber content was found to decrease the compressive strength of the concrete. Figures 3 and 4 below show the graphical plot of the compressive and tensile strengths of the concrete specimens for both curing periods.

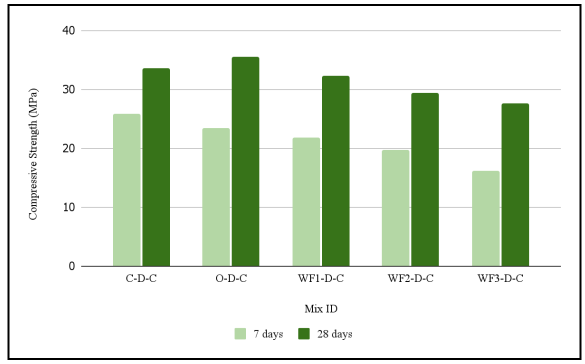

Fig. 3. Compressive Strength of Concrete Specimens

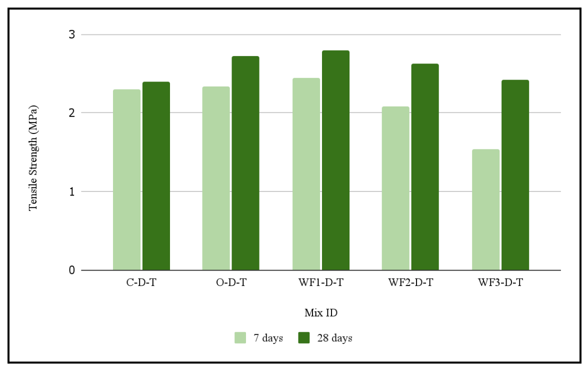

Fig. 4. Tensile Strength of Concrete Specimens

According to Liao et al. (2020), tensile strength of concrete typically accounts for 7-15% of its compressive strength. The results from this study demonstrated that after 7 days of curing, the tensile strength ranged from 8.89% to 11.27% of compressive strength, with sample WF1-D7 showing the highest percentage. At 28 days, the tensile strength percentage ranged from 7.15% to 8.92%, all falling within the same 7-15% range.

Table 11. Percentage of Tensile Strength for 7 Days

Mix ID	Ave. Tensile Strength (MPa)	Ave. fc' (MPa)	% of Tensile Strength
C-D7	2.3	25.87	8.89%
O-D7	2.33	23.47	9.93%
WF1-D7	2.45	21.74	11.27%
WF2-D7	2.08	19.66	10.58%
WF3-D7	1.54	16.22	9.49%

Table 12. Percentage of Tensile Strength for 28 Days

Mix ID	Ave. Tensile Strength (MPa)	Ave. fc' (MPa)	% of Tensile Strength
C-D28	2.4	33.58	7.15%
O-D28	2.72	35.47	7.67%
WF1-D28	2.8	32.26	8.68%
WF2-D28	2.62	29.38	8.92%
WF3-D28	2.42	27.58	8.77%

Table 13. Comparison of the compressive strength of Kiptum et.al & Present study

	Kiptum et al. (2019)		Present Study	
% of add. fibers	fc' (MPa)	% Change	fc' (MPa)	% Change
0	26.18	-	33.58	-
0.1	18.94	-27.65%	32.26	-3.93%
0.2	18.12	-30.79%	29.38	-12.51%
0.3	16.32	-37.66 %	27.58	-17.87%

Similar findings were reported by Kiptum et al. (2019), where concrete without fibers attained a compressive strength of 28.06 MPa, while incorporating 0.1% of WHF resulted in a reduced strength of 27.5 MPa. This trend persisted up to a 0.3% addition of WHF, aligning with the outcomes observed in the present study. The study of Dayananda et al. (2018) obtained analogous results when incorporating jute fibers into concrete. This phenomenon can be attributed to the excessive addition of fibers which generates voids or empty spaces, thereby compromising the internal strength of the concrete. Consequently, a higher fiber content leads to reduced compaction levels and a subsequent decrease in the compressive strength of the concrete.

3.4 Workability

Table 14. Workability of Mortar Specimens

Mix Code	Flow Table Test Result (mm)
W0F0	148.70
W10F0	136.20
W0F30	165.26
W5F25	158.11
W10F20	148.54
W15F15	128.45
W20F10	115.11
W25F5	106.88

As shown in Table 14 the W0F30 mixture exhibited the highest workability. Meanwhile only the W5F25 mixture, containing both WHA and FA, demonstrated a higher flow than the control mixture. Overall, an increase in the amount of WHA led to a decrease in workability, despite several studies' suggestions that a higher WHA content can enhance workability (Balasundaram & Murugesh, 2017). In contrast, the inclusion of FA generally improved workability and cohesiveness due to its fine particles which reduced bleeding and segregation, especially in lean mixes (Rosenberg, 2010). FA's limited binding properties resulted in higher slump values, which were influenced by the water/cement ratio and mix design. Slump tests on mixtures with varying FA percentages demonstrated that FA positively affected workability, with its fine, siliceous particles helping achieve the desired slump and improving the fresh state of concrete (Mahajan et al., 2020).

Table 15. Workability of Concrete Specimens

Mix Code	Slump Result (mm)
C	80
O	150
WF1	110
WF2	100
WF3	90

Table 15 exhibits that the slump decreases as fiber content increases, likely due to the high water absorption of the fibers. A similar trend was observed by Niyasom & Tangboriboon (2021) where fibers increased water absorption and reduced slump. The concrete mix with optimal cement replacements recorded a higher slump (150 mm) compared to the control mix (80 mm), supporting the third hypothesis that the cement-replacement mix was more workable.

4. CONCLUSIONS

The study reached the following conclusions:

The mix W5F25, containing 5% of WHA and 25% of FA as cement replacements, resulted in the highest compressive strength for mortar, with 19.41 MPa and 25.29 MPa for 7- and 28-curing days, respectively.

The ratio from phase one was applied with varying additions of WHF at 0.1%, 0.2%, and 0.3%.The addition of WHF increased the split tensile strength of concrete. The addition of 0.1% WHF, mix ID WF1, resulted in a higher split tensile strength compared to the optimal mix without fiber addition, averaging 2.80 MPa compared to the latter's 2.72 MPa. Despite the reduction in compressive strength between mix O and the WHF mixes, the highest mean tensile strength was from the 0.1% WHF mix.

The workability of the mortar for phase one decreased as the amount of WHA increased. Similarly, concrete workability for phase two also decreased as the fiber replacement increased due to the fibers' high-water absorption.

To enhance the study, future research should focus on analyzing compressive strengths at extended curing periods, exploring different fiber orientations and lengths, applying the findings to various structural materials like beams, slabs, and hollow blocks, and further investigating the combined effects of WHA and FA on concrete properties.

5. ACKNOWLEDGMENTS

The authors wish to express their heartfelt gratitude to God for His grace and guidance, and to their families for their unwavering support and encouragement. They also extend their appreciation to the faculty and staff of De La Salle University (DLSU) for their invaluable assistance, input, and provisions during the research. Special thanks are also given to the Cardona Water Hyacinth Primary Processing Center, Pozzolanic Philippines Inc., and DOST-PTRI for their support.

6. REFERENCES

Abirami, U., Kayalvizhi, K., Pavithra, K., & Govandan, A., (2018). Experimental Study on Behaviour of Concrete Replaced with Water Hyacinth Ash. International Journal of Engineering Research & Technology, 6(14).

Abushad, M., & Sabri, M. D. (2017). Comparative Study of Compressive Strength of Concrete with Fly Ash Replacement by Cement. *International Research Journal of Engineering and Technology (IRJET), 4*(7), 2627–2630. https://www.irjet.net/archives/V4/i7/ IRJET-V4I7534.pdf

Ahmaruzzaman, M. (2010). A review on the utilization of fly ash. Progress in Energy and Combustion Science, 36(3), 327–363. https://doi.org/10.1016/j.pecs.2009.11.003

Balasundaram, N., & Murugesh, V. (2017). Experimental Investigation on water hyacinth ash as the partial replacement of cement in concrete. International Journal of Civil Engineering and Technology (IJCIET), 8(9), 1013–1018. http://http//iaeme.com/Home/issue/IJCIET?Volume=8 &Issue=9

Das, N., & Singh, S. (2016). Evaluation of water hyacinth stem ash as pozzolanic material for use in blended cement. Journal of Civil Engineering, Science and Technology, 7(1), 1–8. https://doi.org/ 10.33736/jcest.150.2016

Dayananda, N., Gowda, B. S. K., & Prasad, G. L. E. (2018). A study on compressive strength attributes of jute fiber reinforced cement concrete composites. IOP Conference Series. Materials Science and Engineering, 376, 012069. https://doi.org/10.1088/1757-899x/376/ 1/012069

Ebben, A., & Carlson, C. (2020). Value in Waste: Fly Ash Reuse and Recovery Opportunities. Feeco International. https://feeco.com/value-in-waste-fly-ash-reuse-and-recovery-opportunities/

Harun, I., Pushiri, H., Amirul-Aiman, A. J., & Zulkeflee, Z. (2021). Invasive Water Hyacinth: Ecology, Impacts and Prospects for the Rural Economy. Plants, 10(8), 1613. https://doi.org/10.3390/plants10081613

Hodhod, H., Anwar, M., & Makhlouf, A. (2003). Durability of Water Hyacinth Ash Concrete. Engineering Research Journal, 87, 144-156.

Imbabi, C., & McKenna, S. A. (2012). Trends and developments in green cement and concrete technology. International Journal of Sustainable Built Environment, 1(2), 194–216. https://doi.org/10.1016/j.ijsbe. 2013.05.001

Jamora, J., Gudia, S., Go, A., Giduquio, M., & Loretero, M. (2020). Potential CO2 reduction and cost evaluation in use and transport of coal ash as cement replacement: A case in the Philippines, Waste Management, Volume 103, Pages 137-145, ISSN 0956-053X, https://doi.org/10.1016/j.wasman.2019.12.026.

Joshi, R. (2017). Effect on compressive strength of concrete by partial replacement of cement with fly ash. *International Research Journal of Engineering and Technology, 4*(2), 315-318.

Kamal, M., Shaheen, Y., El-Sayed M. & Omran, A. (2003). The resistance of Concrete Containing Water Hyacinth Ash (WHA) to Aggressive and Destructive Surrounding Conditions. Shebin Elkom, Egypt.

Kiptum, C. K., Rosasi, L., Joseph, O., & Odhiamba, E. (2019). Some mechanical characteristics of concrete reinforced with dried water hyacinth and quarry dust as fine aggregates. Journal of Civil Engineering, Science and Technology, 10(2), 105-111. https://doi.org/10.33736/jcest.1451.2019

Krishnan, S. & Murugesh, V., (2018). Experimental Study on Strength of Water Hyacinth Ash as Partial Replacement of Cement in Concrete. International Journal of Scientific & Engineering Research, 9(3), 93-96.

Liao, W., Chen, P., Hung, C., & Wagh, S. K. (2020). An innovative test method for tensile strength of concrete by applying the Strut-and-Tie methodology. Materials, 13(12), 2776. https://doi.org/10.3390/ma13122776.

Mahajan, L., Mahadik, S., & Bhagat, S. R. (2020). Investigation of Fly Ash Concrete by Slump Cone and Compaction Factor Test. IOP Conference Series: Materials Science and Engineering, 970(1), 012011. https://doi.org/10.1088/1757-899x/970/1/012011

Murugesh, V., & Keziah, R. (2021). Chemical analysis of water hyacinth ash by XRD and SEM. Indian Journal of Advanced Botany, 1(1), 8-10. https://doi.org/10.54105/ijab.b2003.041121

Niyasom, S., & Tangboriboon, N. (2021). Development of biomaterial fillers using eggshells, water hyacinth fibers, and banana fibers for green concrete construction. Construction and Building Materials, 283, 122627. https://doi.org/10.1016/j.conbuildmat.2021.122627

Philippine Statistics Authority (2023). Private Construction Statistics | Philippine Statistics Authority | Republic of the Philippines. Psa.gov.ph. https://psa.gov.ph/statistics/construction/pcs

Rosenberg, A. (2010, May 8). Using Fly Ash in Concrete. NPCA. https://precast.org/blog/using-fly-ash-in-concrete/

Sathawane, S. H., Vairagade, V. S., & Kene, K. S. (2013). Combine effect of rice husk ash and fly ash on concrete by 30% cement replacement. Procedia Engineering, 51, 35–44. https://doi.org/10.1016/j.proeng.2013.01.009

Villamagna, A. M., & Murphy, B. R. (2010). Ecological and socio-economic impacts of invasive water hyacinth (Eichhornia crassipes): a review. Freshwater Biology, 55(2), 282–298. https://doi.org/10.1111/j.1365-2427.2009.02294.x

Yehualaw, M. D., Alemu, M., Hailemariam, B. Z., Vo, D., & Taffese, W. Z. (2022). Aquatic weed for concrete sustainability. Sustainability, 14(23), 15501. https://doi.org/10.3390/su142315501