Malaysian
Journal Of
Civil
Engineering

BEHAVIOR OF CONCRETE COMPRESSIVE STRENGTH BY UTILIZING FLY ASH AND WOOD POWDER

Tarikul Islam*, Sristi Das Gupta, Julekha Janin, Ataur Rahman

Department of Civil Engineering, Ahsanullah University of Science and Technology (AUST), Dhaka, Bangladesh

Article history
Received
21 July 2021
Received in revised form
25 September 2021
Accepted
30 September 2021
Published online
30 November 2021

*Corresponding author
tarik4523.ce@aust.edu

Abstract

The release of CO_2 into the atmosphere, which is caused by cement manufacturing, is a substantial cause of global warming. Besides, rapid industrial expansion has prompted concerns about how to properly dispose of industrial by-products. Many of them might pollute the environment if discarded in open landfills. In recent years, utilization of natural and industrial waste as a supplement to cement or aggregates has become incredibly popular as a means of improving concrete performance, satisfy rising cement needs and achieving environmental sustainability. A blend of fly ash (as a cement substitute) and wood powder (as a fine aggregate substitute) might be a viable alternative for determining the impact on the concrete mixture. In this study, fine aggregate is substituted with 5%, 10%, and 15% wood powder, and cement is replaced with 10%, 15%, and 20% fly ash to get the best combination in terms of compressive strength. When a 5% wood powder replacement is done with fine aggregate and a 10-15% replacement of cement is made with fly ash, compressive strength improves between 2.19-3.58% and 4.12-7.51% for 28 days and 90 days. It is found that if the quantity of wood powder in concrete exceeds 5%, the compressive strength drops dramatically. Besides that, concrete constructed with a 20% fly ash and 15% wood powder mixture disintegrated while curing. However, concrete containing up to 10% wood powder and up to 15% fly ash has been demonstrated to be effective when compared to plain concrete. Furthermore, based on the compressive strength test results of concrete at 28 days and environmental sustainability, a considerable proportion of construction expenses may be saved by substituting 10-15% of cement with fly ash.

Keywords: Fly ash; Wood powder; pozzolanic material; Compressive strength; Environment sustainability

1.0 INTRODUCTION

In recent years, concrete production using alternate materials are being popular throughout the world. The rationale for this is to limit the amount of cement and aggregate used in concrete to reduce GHG emissions. Natural wastes can be utilized as a partial substitute for binder and aggregate in concrete. Additional natural waste in concrete has been shown to improve concrete's overall performance. Directly releasing waste materials into the environment can result in environmental issues. As a result, the importance of reusing waste has been accentuated.

Fly ash is a mineral additive that is advantageous to concrete which is a byproduct of the thermal power plant. It is the most common and widespread pozzolanic material on the planet. However, fly ash particles are almost spherical, with diameters ranging from 0.5 to 150 microns. As a result, fly ash easily integrates into the mix, making it a promising concrete additive (Jatoi et al., 2019). Furthermore, utilizing this waste material in the concrete technology minimizes power plant environmental issues while also lowering energy generating costs.

Several studies looked at the effect of fly ash as a partial substitute for cement and found that a 10% substitution was the optimal in contrast to plain concrete (Goud & Soni, 2016; Kumar Singh et al., 2015). The addition of fly ash boosted the strength after 28 days with a prominent replacement level of 20% (Harison et al., 2014). Cong Kou et al. (2007) indicated that integrating 25–35% fly ash into structural concrete is one of the feasible approaches to employ a high proportion of recycled aggregate while minimizing some of the disadvantages associated with recycled aggregates usage in concrete. Another study concluded that maximum 5% replacement of fly ash is optimal for new constructions with recycle aggregate (Chandio et al., 2020). The pozzolanic activity of fly ash is significantly increased when it is crushed to enhance fineness, according to several studies. However, it has been observed that increasing the specific surface area above 6,000 cm^2/g has little impact on pozzolanic activity of fly ash (Siddique & Khan, 2011). Using fly ash in concrete aims at the reduction of cement usage, workability improvement, reduction of heat of hydration in mass concreting, enhancement of ultimate strength, reduction of permeability, corrosion resistance and attaining targeted strength beyond 56 days (Siddique & Khan, 2011).

Wood powder, also known as wooden dust, contains fine wood particles obtained by sawing, drilling or grinding of wood and filtered to the right size. It is not widely available as sand or gravel in significant amounts and use for concrete production has been discouraged. Sawdust has some severe health and environmental consequences when dumped in landfills and streams or burned in the open air (Mwango & Kambole, 2019). Due to rising demands in the construction industry for developing nations to keep construction costs low and achieve a sustainable environment, the use of locally available waste materials as a partial substitute for building materials has increased recently. Abdullahi, et al. (2013) investigated the use of raw sawdust in concrete mix and concluded that due to the air-entraining property it cannot be used for mass concrete production. Because the inclusion of sawdust in the concrete mix more than 10% results in a significant reduction of compressive strength (Abdullahi, et al., 2013; Abed & Khaleel, 2019). Again, the addition of sawdust to concrete enhanced its crack resistance due to the uniformly distributed grains, which are comparable to fiber (Ahmed et al., 2018). However, the majority of prior research found that 5 to 15% fine aggregate substitution with sawdust in concrete mix results in comparative strength to plain concrete (Huda Suliman et al., 2019; Lakshmi TK & Dilip P, 2019; Narayanan et al., 2018; Nathan, 2018; Yakubu & Bukar, 2020).

Based on the findings of the previous study, it has seemed that using a combination of fly ash (as a cement substitute) and wood powder (as a fine aggregate substitute) to explore the influence on the concrete mixture would be a viable choice. To get the optimum blend considering compressive strength, the fine aggregate would be replaced by 5%, 10% and 15% wood powder and cement would be replaced by 10%, 15% and 20% fly ash in this study.

2.0 MATERIALS AND METHODS

2.1 Cement

Ordinary Portland cement (OPC) with a 52.5 N strength class was utilized in this investigation. This cement took 45 minutes to set initially, and after two days, it had a strength of 20 MPa. OPC is made up of 95-100 percent clinker and 0-5 percent gypsum, and has a specific gravity of 3.13.

2.2 Aggregates

Coarse sand was used as the fine aggregate, while crushed stone chips were used as the coarse aggregate.
Table *1* shows the aggregates' physical characteristics.

Table 1 Aggregate physical properties

Physical Property	Fine aggregate	Coarse aggregate	Wood powder
Bulk Specific Gravity (OD Basis)	2.54	2.65	0.35
Absorption Capacity (%)	1.34	0.72	12.57
Fineness Modulus (FM)	2.59	-	3.37
Dry Rodded Unit Weight (kg/m^3)	1590	1520	520

2.3 Fly Ash (FA)

The most often utilized types of fly ash in concrete are Class C (high-calcium content) and Class F (low-calcium content). The carbon concentration of class C fly ash is less than 2%, while class F fly ash is between 5% and 10%.**Table 2** demonstrates the physical characteristics of fly ash and

Table 3 illustrates the comparison of chemical characteristics of class C, class F fly ash and OPC. Fly ash of class F (dark grey color) was utilized in this research which was collected from local fly ash suppliers. According to the source, the fly ash used for the research has a specific gravity of 2.75 and comprises 50% SiO_2, 4.6% CaO. To evaluate particle size distribution of fly ash, sieve analysis by washing (ASTM C117-17, 2017) and hydrometer analysis (ASTM D7928 - 17, 2017) were used (**Figure 2**). Fly ash finer than 75 µm is used for this study.

Table 2: Physical Properties of Fly ash (FA) (Siddique & Khan, 2011)

Physical Property	Range/Description
Size	10 µm to 100 µm (finer than OPC)
Shape	Spherical
Color	Tan (higher lime content) Dark grey (elevated unburned carbon content) Brown (iron content)
Retained on 5µm (#325) sieve (%)	3.55 to 36.90
Specific Gravity	1.3 to 4.8
Moisture content	0 to 0.38 %
Blaine fineness (cm^2/g)	1579 to 5550

Table 3: Chemical comparison between class F fly ash, class C fly ash & OPC

Parameter	Class F fly ash	Class C fly ash	OPC	Reference
SiO_2 (%)	45–64.4	23.1–50.5	17-25	
CaO (%)	0.7–7.5	11.6–29.0	60-67	(Ahmaruzzaman, 2010; Cornejo et al.,
Al_2O_3 (%)	19.6–30.1	13.3–21.3	3-8	2014; Grau et al., 2015; Jahagirdar et al.,
Fe_2O_3 (%)	3.8–23.9	3.7–22.5	0.5-6	2019; Marchment et al., 2019; Nath &
Na_2O (%)	0.3–2.8	0.5–7.3	0.2-0.5	Sarker, 2011; Paul et al., 2019; Sata et al.,
MgO (%)	0.7–1.7	1.5–7.5	0.5-4	2007; Siddique et al., 2016; Siddique &
K_2O (%)	0.7–2.9	0.4–1.9	0.35-0.53	Khan, 2011)
Loss on ignition (LOI)	0.4–7.2	0.3–1.9d	<3	

(a) (b)

Figure 1: (a) Fly ash (Class F) & (b) Wood powder used for the study

2.4 Wood Powder (WP)

Pure wood powder (***Figure 1*b**) is collected from locally available market which has a moisture content of 9.2% and coarser in size than sand. Physical properties of wood powder are shown in

Table *1*. Particle size distributions (**Figure 2**) for coarse sand and wood powder were obtained by sieve analysis (ASTM C136/C136M−19, 2019). The coarser wood powder particles were sieved out using a 4.75 mm sieve.

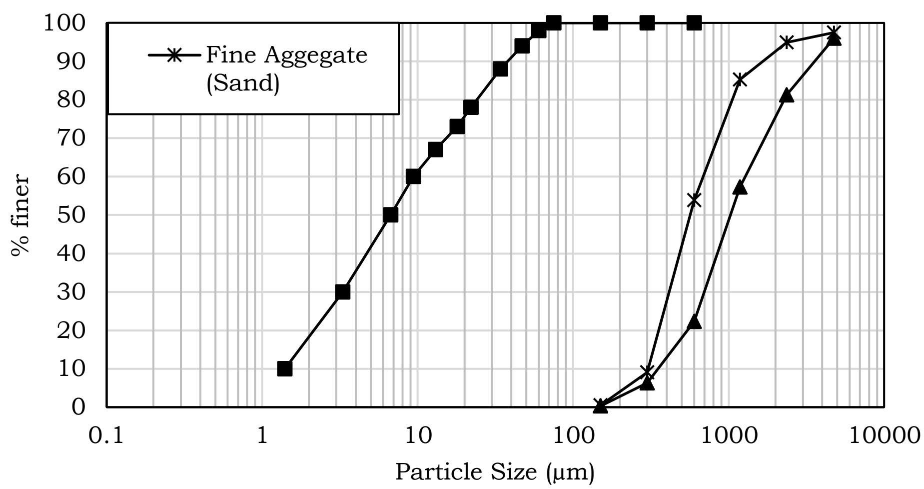


Figure 2: Particle size distribution of coarse sand, wood powder and fly ash used for the study.

2.5 Concrete Mixing

The mix design (**Table 4)** was done in conformance with ACI 211.1-91. After 28 days, the trail mixes were supposed to have a strength of 25 MPa and a slump value of 75-100 mm. Before mixing, aggregates and wood powder were being soaked and surface dry (SSD). A sufficient quantity of fine aggregates (FA), coarse aggregate (CA), cement, fly ash, and wood powder were taken for a two-minute dry mixing period. A slump cone was used to assess concrete workability after it had been mixed with water. The concrete was tamped into the cube with a tamping rod. The new concrete was finished with a smooth steel trowel. The molds are removed after 24 hours, and the test specimens were immersed in a water tank for curing maintaining temperature 27 $\pm$ 2°C until the required test age.

Table 4 Experimental mix design of the concrete

Specimen Designation	Water (kg/m³)	Cement (kg/m³)	Coarse Aggregate (kg/m³)	Fine Aggregate (kg/m³)	Fly ash (kg/m³)	Wood powder (kg/m³)
Plain Concrete (PC)	205	418.5	997	730.5	0	0
F10W5	205	376.65	997	693.975	41.85	36.525
F10W10	205	376.65	997	657.45	41.85	73.05
F10W15	205	376.65	997	620.925	41.85	109.575
F15W5	205	355.725	997	693.975	62.775	36.525
F15W10	205	355.725	997	657.45	62.775	73.05
F15W15	205	355.725	997	620.925	62.775	109.575
F20W5	205	334.8	997	693.975	83.7	36.525
F20W10	205	334.8	997	657.45	83.7	73.05
F20W15	205	334.8	997	620.925	83.7	109.575

2.6 Test for Compressive Strength

The compressive strength test for cube specimens was conducted according to BS EN 12390-3, 2019. The w/b ratio, the quality of cement and concrete materials, quality control during manufacture, and other variables all influence the compressive strength of concrete. Total 60 concrete cubes (150×150×150 mm) were prepared to determine the compressive strength (

Figure *3*). At first, concrete was poured in three levels in the cubes. The top surface was troweled after the final layer was pounded, and each layer was compacted with 32 tamping rod strokes. After a 24-hour period, the specimen was carefully removed from the mold. In each sample, three specimens were examined to assess the compressive strength after 14, 28 and 90 days of curing.

Figure 3: Testing for compressive strength

3.0 RESULTS AND DISCUSSION

3.1 Influence Of Wood Powder As A Replacement Of Fine Aggregate

Several studies have found that replacing fine aggregate in concrete with wood powder reduces compressive strength (Ahmed et al., 2018; Nathan, 2018; Tilak et al., 2018). Huda Suliman et al (Huda Suliman et al., 2019) reported that The quantity of sawdust added to the concrete has had the opposite impact on the cement-sawdust bond, implying that adding more sawdust to the mix will lower the strength of the concrete. High porous particles, availability of initial free water content of sawdust results in a decrement of compressive strength (Ahmed et al., 2018). Some studies have shown that replacing sand with wood powder, up to a certain level, improves compressive strength. Yakubu & Bukar (2020) concluded that for self/internal curing at 7, 14, and 28 days, concrete with a 5% substitution of fine aggregate with wood powder had compressive strengths that were 34.04%, 36.38%, and 30.78% greater than control specimens. Narayanan et al. (2018) claimed up to 15% inclusion of sawdust has comparable compressive strength with control mix. On the other hand, Lakshmi TK & Dilip P (2019) investigated teak wood dust as a sand replacement in concrete and found 9.39% increment for 10% substitution. So, in this study several combinations of wood powder (as sand replacement) and fly ash (as cement replacement) in concrete were explored to obtain the most beneficial mixture in terms of compressive strength.

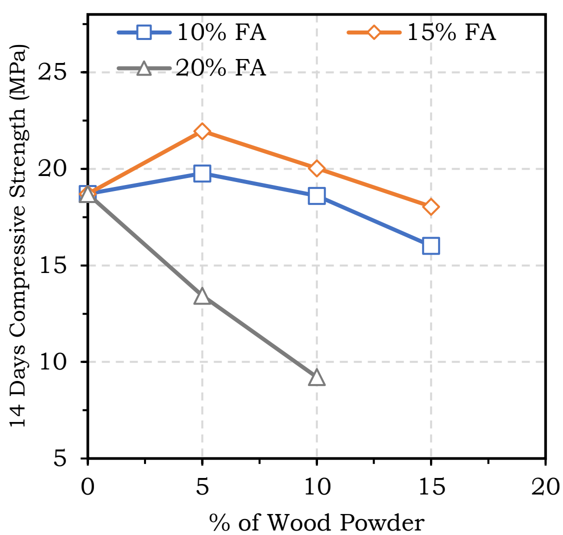
Figure 4 shows compressive strength increases with an incremental percentage of wood powder up to 5% fine aggregate replacement due to the high amount of grain content in wood powder. However, concrete containing up to 10% wood powder as fine aggregate replacement and up to 15% fly ash as cement replacement is found to be effective as compared to the plain concrete. If the percentage of wood powder in concrete increases more than 5%, a remarkable reduction of compressive strength is observed. In comparison with plain concrete, compressive strength increment from 5.72 to 17.43% is obtained for the combination of 5% replacement of fine aggregate with wood powder and 10-15% replacement of cement with fly ash for 14 days (**Figure 5**). Again, with the same replacement combination, compressive strength increment ranges between 2.19-3.58 % and 4.12-7.51% for 28 days and 90 days respectively. Madhavi et al. (2013) reported that 10% cement replacement with fly ash and 20% fine aggregate replacement shows the maximum strength increment of 4.14% at 28 days (Table 5).

Table 5 Comparison of strength effectiveness of wood powder and glass aggregate

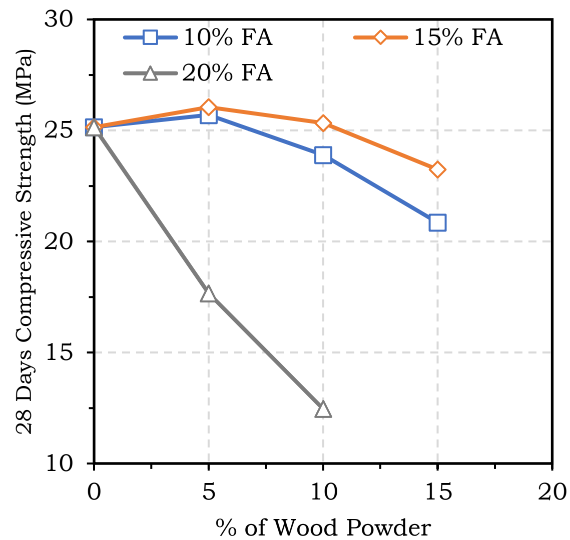
Replacement of cement with Fly ash (%)	Replacement of fine aggregate (%)		Strength effectiveness at 28th day (%)
	Wood Powder	Glass aggregate	
10	5	-	2.19
	-	10	3.38*
	-	20	4.14*
15	5	-	3.58
	10	-	0.76

* Madhavi et al; 2013

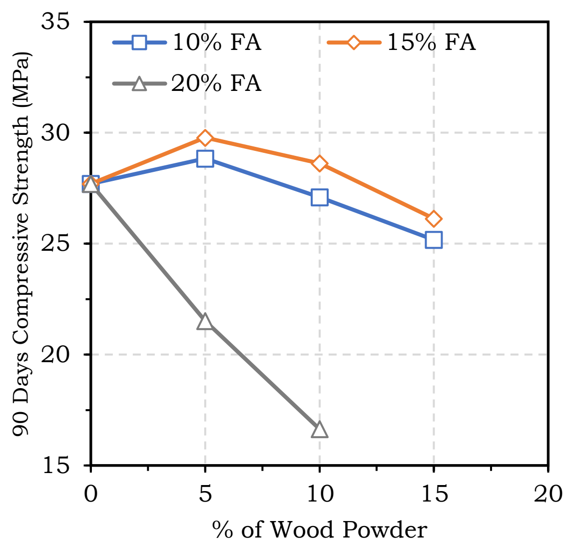
Note: Strength effectiveness (%) = [(strength of sample concrete − strength of plain concrete)/strength of plain concrete] × 100%



(a)



(b)



(c)

Figure 4*:* Comparison of Compressive strength with % of wood powder with various % of Fly ash at (a) 14 days, (b) 28 days & (c) 90 days

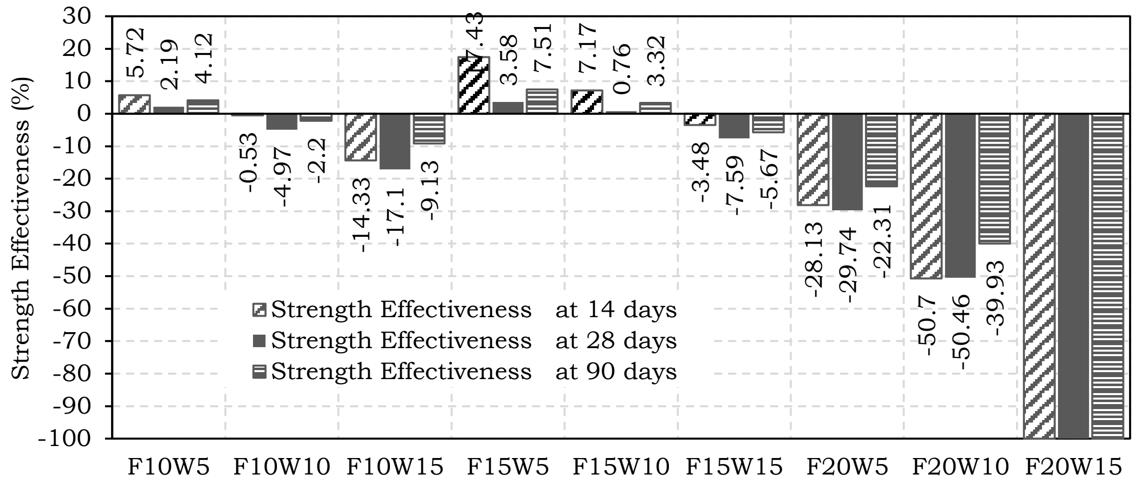
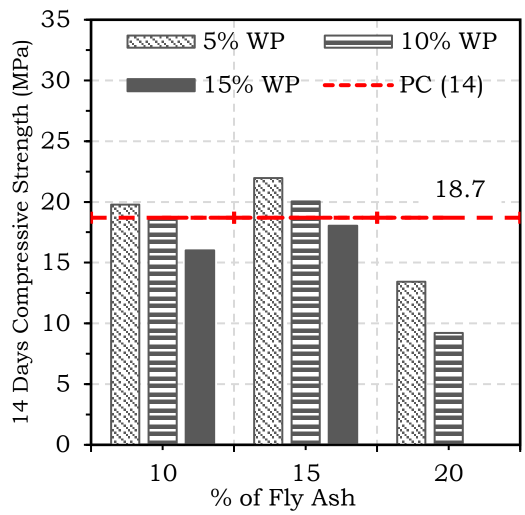
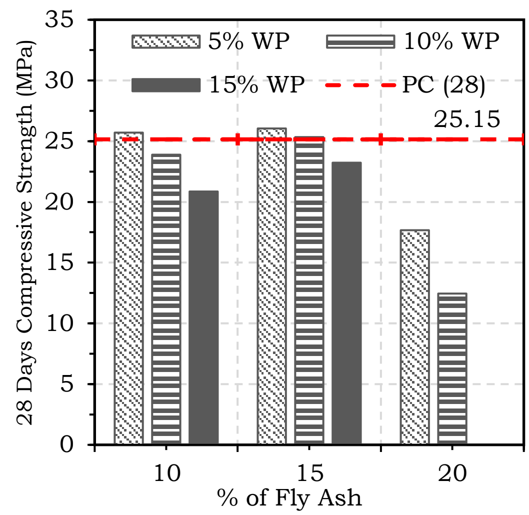


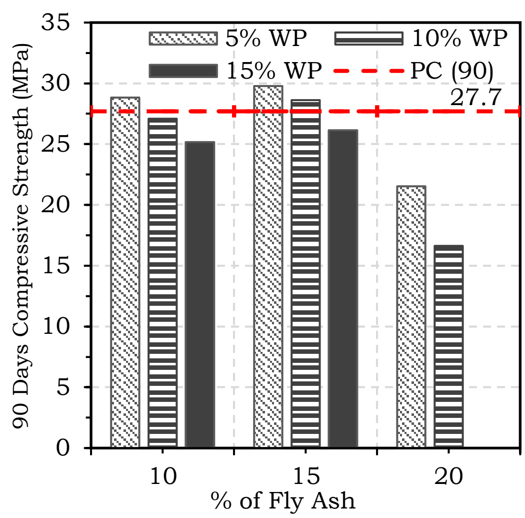
Figure 5: Strength effectiveness of test samples at 14, 28 and 90 days



(a)



(b)



(c)

(d)

Figure 6: Comparison of Compressive strength with % of fly ash with various % of wood powder at (a) 14 days, (b) 28 days, (c) 90 days & (d) curing of F20W15 (Concrete with 20% fly ash and 15% wood powder)

3.2 Influence Of Fly Ash As A Replacement Of Cement

Fly ash is a pozzolanic material that can contribute to strength increment when blended in the concrete mix as a partial substitute of cement by forming C-S-H gel (Kumar Singh et al., 2015). The calcium hydroxide released during the hydration of OPC interacts slowly with the amorphous aluminosilicates, or pozzolanic compounds, contained in fly ash when it is used in concrete. These reactions produce pozzolanic reaction products, which are time-dependent but essentially the same kind and properties as cement hydration products. As a result, more cementitious materials become accessible, increasing the strength of concrete (Siddique & Khan, 2011). **Figure 6** shows the comparison of various percentage of wood powder as fine aggregate replacement with an incremental percentage of fly ash as supplementary cementitious material in concrete. In comparison with the plain concrete, compressive strength increases with an incremental percentage of fly ash up to 15% cement replacement. For 20% cement replacement with fly ash severe decrement in compressive strength is observed. When the fly ash content rises, the pozzolanic reaction slows down resulting in the formation of a porous microstructure because there is not enough calcium hydroxide in the mix to react with all of the available fly ash. Again, this reduction might be attributable to the fact that the volume of fly ash is significantly more than the volume required for void packing in concrete. This increase in volume necessitates the use of additional water for lubrication, lowering compressive strength (Kumar Singh et al., 2015). Moreover, concrete prepared with a combination of 20% fly ash (cement replacement) and 15% wood powder (fine aggregate replacement) showed damaged behavior during curing (**Figure 6**d). It could be happened due to prolonged setting time and difficulty in mixing of high amount of fly ash and wood powder with fine aggregate and cement. Without replacing fine aggregate, Kumar Singh et al. (2015), Goud & Soni (2016) also reported the similar behavior with an optimum 10% replacement of cement with fly ash. Jatoi et al. (2019) investigated Lakhara fly ash and found that substituting 25% of the binder can increase compressive strength by 15%.

3.3 Cost-Effectiveness And Environmental Sustainability

The emission of greenhouse gases (CO_2, NO_x, etc.), dust, SO_x, volatile and non-volatile organic compounds, radioactive metals, and other pollutants are the major environmental concerns in cement manufacturing (Al Smadi et al., 2009; Capros et al., 2001; Hendriks et al., 1999; Humphreys & Mahasenan, 2002; Josa et al., 2007; Potgieter, 2012; Saheed Bada et al., 2013). To attain sustainability, hygiene and health safety natural and industrial wastes having pozzolanic characteristics are increasingly being used as supplemental cementitious materials (Bertolini et al., 2004; Madurwar et al., 2013; Martirena & Monzó, 2018; Mishra & Siddiqui, 2014; Sakir et al., 2020; Siddique, 2010). However, these supplementary materials have a huge impact on cost reduction. Wood powder is a natural by products and available in considerable amounts. Though it costs lower than sand, for the cost analysis the price of WP is considered same as sand. In the context of Bangladesh, considering the cost of cement around 450 Tk per bag (50 kg) and fly ash as 2.55 Tk/kg, the cost reduction is found to be 7.17-10.75% with a 10-15% addition of fly ash. Based on concrete compressive strength test results at 28 days and environmental sustainability, a 15% cement replacement (**Figure 7**) saves 10.75 % construction costs and reduces the production and release of gases that are detrimental to the environment.

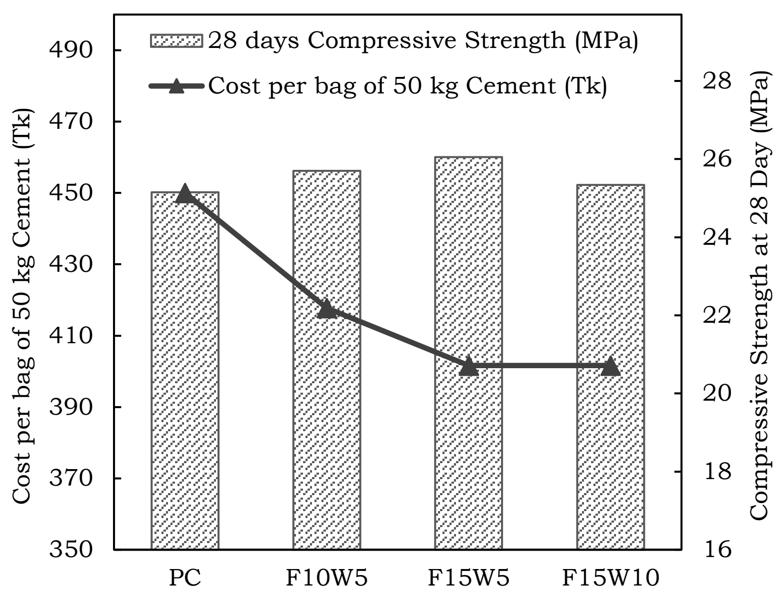


Figure 7: Reduction of cost considering compressive strength at different replacement level of cement

4.0 CONCLUSIONS

Fly ash (FA) from the coal-based thermal power plant is considered as hazardous waste which is detrimental to the environment. The chemical composition of FA suggests that it might be utilized as pozzolanic material for the concrete mix as a supplemental cementitious material. The majority of the studies found that using FA as a cement substitute up to a specific proportion yielded equivalent results in terms of compressive strength. On the other hand, natural waste wood powder may be utilized as a fine aggregate substitute. However, using a mix of fly ash and wood powder in concrete to increase compressive strength may be a viable option. It also has the potential to lower construction costs and greenhouse gas emissions. Following are the findings that may be drawn following the completion of the tests and analysis of the results:

- Due to the high amount of grain content in wood powder, the compressive strength rises with an increasing percentage of wood powder up to 5% fine aggregate replacement. For 14 days, a combination of 5% replacement of fine aggregate with wood powder and 10-15% replacement of cement with fly ash increased compressive strength from 5.72 to 17.43 % as compared to plain concrete.
- Compressive strength increases between 2.19-3.58% and 4.12-7.51% for 28 days and 90 days, respectively, with the same replacement combination.
- A drastic drop in compressive strength is found when the proportion of wood powder in concrete exceeds 5%.
- However, in comparison to the plain concrete, concrete having up to 10% wood powder as fine aggregate replacement and up to 15% fly ash as cement replacement is shown to be effective.
- When 20% of the cement is replaced with fly ash, the compressive strength is significantly reduced. Furthermore, concrete made with a mixture of 20% fly ash and 15% wood powder exhibited demolished behavior during curing. It may have occurred as a result of the extended setting time and difficulties combining a large volume replacement of cement and fine aggregate with fly ash and wood powder. Moreover, considering concrete compressive strength test results at 28 days and environmental sustainability, 7.17-10.75% construction expenses can be saved by 10-15% cement replacement with FA.

Acknowledgements

The material and testing support from concrete and geo-technical laboratory of Ahsanullah University of Science and Technology (AUST) has gratefully confessed.

References

[1] Abdullahi, A., Abubakar, M., & Afolayan, A. 2013. Partial Replacement of Sand with Sawdust in Concrete Production. *3rd Biennial Engineering Conference, Federal University of Technology, Minna,* 1–6. https://doi.org/10.13140/2.1.2742.0804

[2] Abed, J. M., & Khaleel, B. A. 2019. Effect of wood waste as a partial replacement of cement, fine and coarse aggregate on physical and mechanical properties of concrete blocks units. *International Journal of Integrated Engineering*, *11*(8): 229–239. https://doi.org/10.30880/ijie.2019.11.08.023

[3] ACI 211.1-91. 2009. Standard Practice for Selecting Proportions for Normal, Heavyweight and Mass Concrete (Reapproved 2009). *American Concrete Institute, Farmington Hills, MI, 48331-3439 USA.* //www.concrete.org/

[4] 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

[5] Ahmed, W., Khushnood, R. A., Memon, S. A., Ahmad, S., Baloch, W. L., & Usman, M. 2018 Effective use of sawdust for the production of eco-friendly and thermal-energy efficient normal weight and lightweight concretes with tailored fracture properties. *Journal of Cleaner Production*, *184*(October): 1016–1027. https://doi.org/10.1016/j.jclepro.2018.03.009

[6] Al Smadi, B. M., Al-Zboon, K. K., & Shatnawi, K. M. 2009. Assessment of air pollutants emissions from a cement plant: A case study in Jordan. *Jordan Journal of Civil Engineering*, *3*(3): 265–282.

[7] ASTM C117-17. 2017. Standard Test Method for Materials Finer than 75-μm (No. 200) Sieve in Mineral Aggregates by Washing. *ASTM International, West Conshohocken, PA*. https://www.astm.org/Standards/C117.htm

[8] ASTM C136/C136M−19. 2019. Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates. *ASTM International, West Conshohocken, PA*, 1–5. https://doi.org/10.1520/C0136_C0136M-19

[9] ASTM D7928 - 17. 2017. Standard Test Method for Particle-Size Distribution (Gradation) of Fine-Grained Soils Using the Sedimentation (Hydrometer) Analysis. *Annual Book of ASTM Standards 2017*, *May 2016*, 1–25. https://doi.org/10.1520/D7928-16E01

[10] Bertolini, L., Carsana, M., Cassago, D., Curzio, A. Q., & Collepardi, M. 2004. MSWI ashes as mineral additions in concrete. *Cement and Concrete Research*, *34*(10): 1899–1906. https://doi.org/10.1016/j.cemconres.2004.02.001

[11] BS EN 12390-3. 2019. Testing hardened concrete - Part 3: Compressive strength of test specimens. *European Committee for Standardization, Avenue Marnix 17, B-1000 Brussels, Belgium*, 4–10.

[12] Capros, P., Kouvaritakis, N., & Mantzos, L. 2001. Economic Evaluation of Sectoral Emission Reduction Objectives for Climate Change - Top-down Analysis of Greenhouse Gas Emission Reduction Possibilities in the EU. *Analysis*, 120. http://europa.eu.int/comm/environment/enveco/climate_change/sectoral_objectives.htm

[13] Chandio, S. A., Memon, B. A., Oad, M., Chandio, F. A., & Memon, M. U. 2020. Effect of Fly Ash on the Compressive Strength of Green Concrete. *Engineering, Technology & Applied Science Research*, *10*(3): 5728–5731. https://doi.org/10.48084/etasr.3499

[14] Cong Kou, S., Sun Poon, C., & Chang, D. 2007. Influence of Fly Ash as Cement Replacement on the Properties of Recycled Aggregate Concrete. *Journal of Materials in Civil Engineering*, *8*(5), 709–717. https://doi.org/10.1061/(ASCE)0899-1561(2007)19:9(709)

[15] Cornejo, M. H., Elsen, J., Baykara, H., & Paredes, C. 2014. Hydration process of zeolite-rich tuffs and siltstone-blended cement pastes at low W/B ratio, under wet curing condition. *European Journal of Environmental and Civil Engineering*, *18*(6): 629–651. https://doi.org/10.1080/19648189.2014.897005

[16] Goud, V., & Soni, N. 2016. Partial Replacement of Cement with Fly Ash In Concrete And Its Effect. *IOSR Journal of Engineering (IOSRJEN)*, *06*(10): 69–75. www.iosrjen.org

[17] Grau, F., Choo, H., Hu, J. W., & Jung, J. 2015. Engineering behavior and characteristics of wood ash and sugarcane bagasse ash. *Materials*, *8*(10): 6962–6977. https://doi.org/10.3390/ma8105353

[18] Harison, A., Srivastava, V., & Herbert, A. 2014. Effect of Fly Ash on Compressive Strength of Portland Pozzolona Cement Concrete. *Journal of Academia and Industrial Research (JAIR)*, *2*(8): 476–479. https://www.researchgate.net/publication/268688940_Effect_of_Fly_Ash_on_Compressive_Strength_of_Portland_Pozzolona_Cement_Concrete/stats

[19] Hendriks, C. A., Worrell, E., Price, L., Martin, N., Ozawa Meida, L.,

de Jager, D., & Riemer, P. 1999. Emission reduction of greenhouse gases from the cement industry. *Greenhouse Gas Control Technologies 4*: 939–944. https://doi.org/10.1016/b978-008043018-8/50150-8

[20] Huda Suliman, N., Atif Abdul Razak, A., Mansor, H., Alisibramulisi, A., & Mohd Amin, N. 2019. Concrete using sawdust as partial replacement of sand : Is it strong and does not endanger health? *MATEC Web of Conferences*, *258*(January): 01015. https://doi.org/10.1051/matecconf/201925801015

[21] Humphreys, K., & Mahasenan, M. 2002. *Towards a sustainable cement industry. Substudy 8: climate change*. https://www.osti.gov/etdeweb/biblio/20269589

[22] Jahagirdar, S., Patki, V., & Metan, S. 2019. Evaluation of physical and chemical properties of OPC and PPC cement. *International Journal of Recent Technology and Engineering*, *8*(2) Special Issue 11), 840–845. https://doi.org/10.35940/ijrte.B1138.0982S1119

[23] Jatoi, M. A., Solangi, G. S., Shaikh, F. A., Khan, S., & Ahmed, S. 2019. Effect of Lakhra Fly Ash as Partial Replacement of Cement in Traditional Concrete. *Mehran University Research Journal of Engineering and Technology*, *38*(4): 1045–1056. https://doi.org/10.22581/muet1982.1904.16

[24] Josa, A., Aguado, A., Cardim, A., & Byars, E. 2007. Comparative analysis of the life cycle impact assessment of available cement inventories in the EU. *Cement and Concrete Research*, *37*(5): 781–788. https://doi.org/10.1016/j.cemconres.2007.02.004

[25] Kumar Singh, V., Srivastava, V., Agarwal, V., & Harison, A. 2015. Effect of Fly Ash as Partial Replacement of Cement in PPC Concrete. *International Journal of Innovative Research in Science, Engineering and Technology*, *4*(7): 6212–6217. https://doi.org/10.15680/IJIRSET.2015.0407193

[26] Lakshmi TK, A., & Dilip P, P. (2019). Experimental Study on Partial Replacement of Sand by Teak Wood Dust in Concrete. *International Journal of Science and Research (IJSR)*, *8*(5), 1804–1808. https://www.ijsr.net/archive/v8i5/ART20198294.pdf

[27] Madhavi, T. P., Sampathkumar, V., & Gunasekaran, P. 2013. Partial Replacement of Cement and Fine Aggregate By Using Fly Ash and Glass Aggregate. *International Journal of Research in Engineering and Technology*, *02*(13): 351–355. https://doi.org/10.15623/ijret.2013.0213066

[28] Madurwar, M. V., Ralegaonkar, R. V., & Mandavgane, S. A. 2013. Application of agro-waste for sustainable construction materials: A review. *Construction and Building Materials*, *38*(January 2019): 872–878. https://doi.org/10.1016/j.conbuildmat.2012.09.011

[29] Marchment, T., Sanjayan, J. G., Nematollahi, B., & Xia, M. 2019. Interlayer Strength of 3D Printed Concrete. In *3D Concrete Printing Technology* (Issue 3). Elsevier Inc. https://doi.org/10.1016/b978-0-12-815481-6.00012-9

[30] Martirena, F., & Monzó, J. 2018. Vegetable ashes as Supplementary Cementitious Materials. *Cement and Concrete Research*, *114*: 57–64. https://doi.org/10.1016/j.cemconres.2017.08.015

[31] Mishra, S., & Siddiqui, N. A. 2014. A Review On Environmental and Health Impacts Of Cement Manufacturing Emissions. *International Journal of Geology, Agriculture and Environmental Sciences*, *2*(3 June 2014), 2. www.woarjournals.org/IJGAES

[32] Mwango, A., & Kambole, C. 2019. Engineering Characteristics and Potential Increased Utilisation of Sawdust Composites in Construction—A Review. *Journal of Building Construction and Planning Research*, *07*(03): 59–88. https://doi.org/10.4236/jbcpr.2019.73005

[33] Narayanan, A., G, H., K, S., & Mary, A. 2018. Replacement of Fine Aggregate With Sawdust. *International Journal of Advanced Research in Basic Engineering Sciences and Technology*, *9*(5): 408–419.

[34] Nath, P., & Sarker, P. 2011. Effect of fly ash on the durability properties of high strength concrete. *Procedia Engineering*, *14*: 1149–1156. https://doi.org/10.1016/j.proeng.2011.07.144

[35] Nathan, M. V. (2018). Effect of Sawdust as Fine Aggregate In Concrete Mixture. *International Journal of Engineering and Techniques*, *4*(3): 1–12.

[36] Paul, S. C., Mbewe, P. B. K., Kong, S. Y., & Šavija, B. (2019). Agricultural solid waste as source of supplementary cementitious materials in developing countries. *Materials*, *12*(7): Article number 1112. ttps://doi.org/10.3390/ma12071112

[37] Potgieter, J. H. (2012). An Overview of Cement production: How “green” and sustainable is the industry? *Environmental Management and Sustainable Development*, *1*(2): 14–37. https://doi.org/10.5296/emsd.v1i2.1872

[38] Saheed Bada, B., Olatunde, K. A., & Oluwajana, A. 2013. Air Quality Assessment in the Vicinity of Cement Company. *International Research Journal of Natural Sciences*, *1*(2): 34–42. https://www.eajournals.org/wp-content/uploads/AIR-QUALITY-ASSESSMENT-IN-THE-VICINITY-OF-CEMENT-COMPANY.pdf

[39] Sakir, S., Raman, S. N., Safiuddin, M., Amrul Kaish, A. B. M., & Mutalib, A. A. (2020). Utilization of by-products and wastes as supplementary cementitious materials in structural mortar for sustainable construction. *Sustainability (Switzerland)*, *12*(9): https://doi.org/10.3390/su12093888

[40] Sata, V., Jaturapitakkul, C., & Kiattikomol, K. 2007. Influence of pozzolan from various by-product materials on mechanical properties of high-strength concrete. *Construction and Building Materials*, *21*(7): 1589–1598. https://doi.org/10.1016/j.conbuildmat.2005.09.011

[41] Siddique, R. 2010. Use of municipal solid waste ash in concrete. *Resources, Conservation and Recycling*, *55*(2): 83–91. https://doi.org/10.1016/j.resconrec.2010.10.003

[42] Siddique, R., & Khan, M. I. 2011. *Supplementary Cementing Materials*. https://doi.org/10.1007/978-3-642-17866-5

[43] Siddique, R., Nanda, V., Kunal, Kadri, E. H., Iqbal Khan, M., Singh, M., & Rajor, A. 2016. Influence of bacteria on compressive strength and permeation properties of concrete made with cement baghouse filter dust. *Construction and Building Materials*, *106*: 461–469. https://doi.org/10.1016/j.conbuildmat.2015.12.112

[44] Tilak, L. N., M.B, S. K., Manvendra, S., & Niranjan. 2018. Use of Saw Dust as Fine Aggregate in Concrete Mixture. *Isbn 978-1-118-095-35-3*: 220.

[45] Yakubu, B., & Bukar, B. Y. 2020. *Partial Replacement of Fine Aggregates with Wood Dust in Concrete (Compressive Strength Test)*. *7*(4): 177–182.