

Review Article

Jawad Ahmad*, Mohamed Moafak Arbili, Ahmed Farouk Deifalla, Abdeltif Salmi, Ahmed M. Maglad and Fadi Althoeay

Sustainable concrete with partial substitution of paper pulp ash: A review

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Abstract: The paper industry is one of the biggest sources of trash and stands out for its effects on both human health and ecological harmony. However, these waste could also help the building sector become more ecologically friendly. Beyond ecological considerations, modern construction often requires materials to make concrete durable, resisting heavy loads and less harmful environmental influences. This creates opportunities for waste management and practical application. This review provides a detail overview of eco-friendly construction ideas that deal with the practical use of materials that are often discarded (paper pulp ash). The impact they had on the characteristics of the construction material, the best mixture composition, and a discussion of the benefits and drawbacks of the “green” addition received the majority of the attention (paper pulp ash). The essential concrete properties such as consistency, setting time, flowability, compressive strength, flexural strength, tensile strength, and impact strength are reviewed. Furthermore, the cost benefits and environmental benefits of paper pulp ash as construction materials are also discussed. The study concludes by suggesting a line of inquiry for the creation of an environmentally friendly structural material for a sustainable future.

Keywords: concrete, paper pulp ash, strength properties

* **Corresponding author: Jawad Ahmad**, Department of Civil Engineering, Military College of Engineering (NUST), Risalpur, 44000, Pakistan, e-mail: jawadcivil13@scetwah.edu.pk

Mohamed Moafak Arbili: Department of Technical Civil Engineering, Erbil Technical Engineering College, Erbil Polytechnic University, 44001, Erbil, Iraq

Ahmed Farouk Deifalla: Structural Engineering Department, Future University in Egypt, New Cairo 11845, Egypt

Abdeltif Salmi: Department of Civil Engineering, College of Engineering, Prince Sattam Bin Abdulaziz University, Al-kharj, 11942, Saudi Arabia

Ahmed M. Maglad, Fadi Althoeay: Department of Civil Engineering, College of Engineering, Najran University, Najran, Saudi Arabia

1 Introduction

The cement business must deal with problems such as rising energy costs, requirement to limit CO₂ ejections, and delivery of raw materials of appropriate quality [1–5]. Beginning in 1990, it is predicted that cement output would increase steadily. This was anticipated since it is the second-most-consumed resource on Earth, next to water. Especially in developing countries like China and India, where there is a great need for cement for the building of houses and other buildings, the company is growing swiftly [6]. The building industry is always looking for new sustainable resources, which are often chosen from leftovers, owing to the scarcity of raw resources and the environmental effects connected with their exploitation [7–10].

In general, the green economy is related to three areas: environmental, social, and economic, to preserve the standard of living [11]. For constructive conversation requirements, engineers must take into account a structure’s “lifecycle” costs, which include costs for infrastructure design, upkeep, destruction, and recycling throughout the course of its useful life. To build sustainably, it is necessary to pay close attention to available physical, environmental, and technical resources as well as issues with human health, energy conservation for both existing and future structures, and management of construction technologies and procedures. A new generation of environmentally friendly materials is really required in order to increase durability and energy efficiency, as well as to enable recycling rate and cost reductions [12–19].

It becomes more common for diverse waste kinds to be produced in varying volumes and quality. Therefore, using new solid sustainability practices to create effective plans for collection, transportation, and processing technologies in accordance with academic and engineering techniques have become necessary to maintain and protect human health in urban communities and to increase methodical productive capacity at all phases of waste disposal [20–24]. Paper trash has been discovered as a

significant component of solid waste, and it is being examined whether it can be recycled into a variety of new goods, particularly in the building and construction industry.

The pulp and paper companies have long been seen as major users of supplies such as wood and water, as well as of energy in the form of electricity, and significant contributors to environmental pollution releases. The demand for pulp cannot be met locally in many regions of the globe, which has prompted the paper industry to look for non-wood raw sources [25]. Global estimates place the annual use of items made from the paper pulp at over 500 million tons [26], or around 58 kg per person. It is anticipated that it will contribute between 2 and 5% of the overall output of paper and pulp, depending on the technology used (on a fresh weight basis). Additionally, a significant volume of wastewater releases up to 0.1 million tons of contaminants into the environment each year [27]. According to research, Nigeria produces an excess of wasted organic (biodegradable) papers, which calls for their alternative, economically viable usage in order to reduce environmental deterioration and health risks [28]. The pulp sectors' present difficulties include producing high-quality pulp at a cheap price while protecting the environment by using progressively less energy, water, and raw materials [25]. The applicability of various binders for materials based on paper pulp composites has been studied. Figure 1 illustrates how the paper could have an impact on ecological quality. Additionally, utilizing wastepaper as a substitute for cement has two advantages. The first is maintaining environmental quality, and the second is that it may be used in lieu of cement to produce concrete [29].

Research on the hydraulic properties, sensitivity, and potential use of paper ash waste as cementing ingredients have been done previously. At temperatures between 700 and 750°C, research [30] showed that paper waste ash may be transformed into sticky lime compounds. According to research [31], biochar made from chicken litter, rice husk and pulp, and papermill sludge was used as a cement binder, replacing cement up to 1% of the overall volume. The authors demonstrate that when contrasted to plain concrete, rice husk biochar, paper mill sludge, and pulp at 0.1% of total volume are the most suitable binders, with similar tensile strength values for the paper pulp and papermill sludge biochar concrete.

The aim of this study is to advance the modern knowledge of the use of paper pulp ash for construction materials by evaluating the technological, mineral, and physical characteristics of specimens produced utilizing various substitute proportions of paper pulp ash and connecting those characteristics to the physical behaviors and mineral content of the specimens. This study was conducted to examine current approaches to using waste products (paper pulp) as green additives in concrete and contrast them with more traditional approaches. Waste-based additives provide a long-term solution to the need for concrete preparation by improving the material's mechanical qualities, bringing down the cost of manufacturing, and creating long-term waste disposal options. The present study examines the chemical characteristics, fresh properties, and hardened properties of concrete with varied amounts of paper pulp ash, as well as environmental issues.



Figure 1: Dumped waste paper which causes environmental pollution [29].

2 Chemical compositions of paper pulp ash

The chemical makeup of the mineral admixtures plays a critical role in establishing their usefulness as a component in the cement blending process. Figure 2 depicts the chemical makeup of paper ash. These findings show that the major chemical constituents, $\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3$ (33.59%), are less than 70%. The wastepaper did not meet the specifications for pozzolanic material as stated in ASTM C-618 [32].

This study indicates that silica and lime (CaO) are the main components of wastepaper ash (SiO_2). The major fundamental chemicals required for cement hydration and strength development are lime, silica, and alumina, and their concentrations have a significant impact on the chemical activity of admixtures in cement. Wastepaper had a greater silica concentration than ordinary Portland cement (OPC) did. This suggests that wastepaper ash would lead to outcomes that are adequate in terms of strength. Nevertheless, there was very little alumina present (2.65%). Minimal direct input from alumina increases Portland cement's strength. Low iron oxide concentration (1.74%), which likewise has no impact on cement but aids it and gives it the gray color, functions as a flux to help cement. Other insignificant components like TiO_2 , MnO_2 , and P_2O_5 were less than 1% and had no impact on the strength or other characteristics of cement.



Figure 3: Dry paper pulp [25].

2.1 Preparation of paper pulp ash

Previous research [25] found that wastepaper from the school environment were collected, cut into little pieces using a paper cutter, and then soaked in tap water for three days as presented in Figure 3. The sopped sheets were put into a paper pulping machine, where they were ground to create a slurry of paper pulp. Research that was similar to this one created paper pulp by pounding materials that had been soaked in water for 2 weeks. This ensured smooth grinding and decreased the pulverizing time. Having been moistened, the wet paper was added to the grinding mill [34].

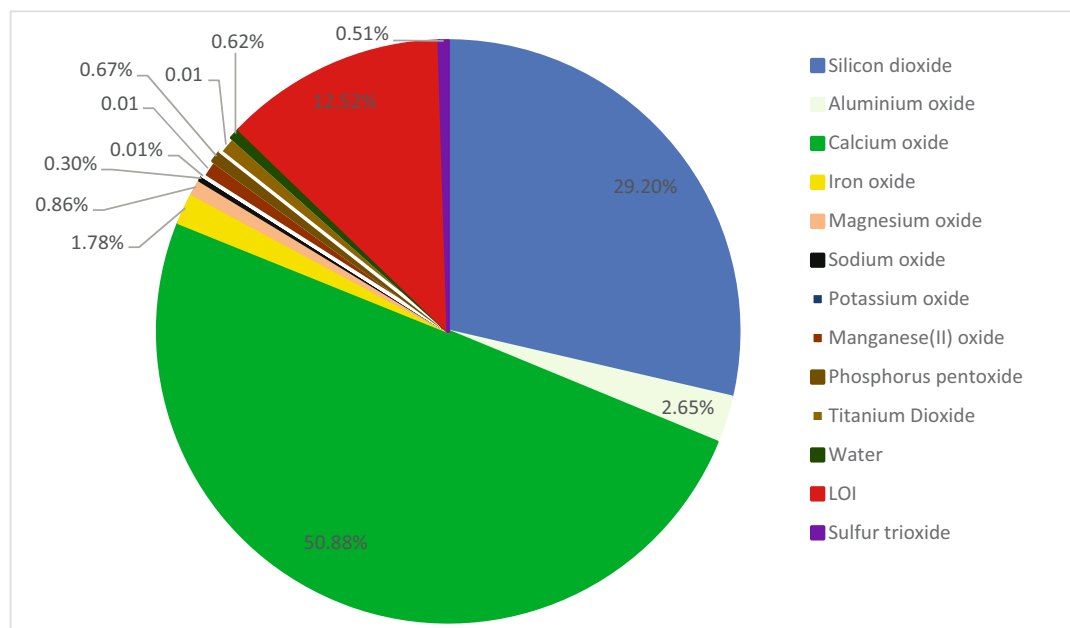


Figure 2: Chemical composition of paper pulp ash [33].

3 Fresh properties

3.1 Consistency

To accomplish the chemical reaction between water and cement, a specific minimum amount of water must be added to the cement. A chemical process would not be completed with less water than this amount, reducing strength, while a chemical reaction with more water could raise the water–cement ratio, increasing strength. In order to get optimum strength while employing cement in construction, the exact proportion of water to cement must be understood. A test of blended cement pastes' usual consistency was conducted in order to get the correct quantity of water. Figure 4 depicts the typical consistency of blended pastes incorporating wastepaper ashes.

The consistency of the control pastes or the paste without wastepaper ash was normal at 29%. In comparison to the control paste, all the pastes containing wastepaper ash displayed normal consistency. The findings fell within this typical range of normal consistency of cement paste between 26 and 33%, and the normal consistency for blended pastes displays a minor rise as the percentage replacement of paper ash increases in comparison to the control paste. The wastepaper pulp ash-containing paste requires more water compared to the control paste or paste without paper pulp ash due to its porosity [29]. The pastes with replacement up to 10% showed uniformity inside this region, but the results after 10% substitution revealed greater levels of consistency [35]. Additionally, the research found that when fly ash (FA) proportion rises from 0 to 20%, the usual consistency rises by roughly 40% [36]. Similar to this, research found that the typical consistency of cement (OPC) is

30.5% and that with 15% silica fume (SF) replacement and 15% metakaolin substitute, it is 37 and 36.37%, respectively. The water consumption is assumed to grow as the replacement level of admixtures rises [37]. It can be concluded that the cementitious materials increased the normal consistency due to their porous nature.

3.2 Setting time

The most crucial factor to consider is the setting time since if the paste is set quickly, it would be difficult to apply it to concrete. There are several variables that affect how quickly pastes are set, including physical and chemical characteristics. According to a study [38], the paste's setting time was accelerated by the greater CaO component. According to a research [39], geopolymer with a high CaO concentration undergoes polymerization and hydration processes, increasing strength and speeding up the paste's setting time. Figure 5 provides the setting times for the blended paste including wastepaper ash.

The typical impact of the paper ash was found to have prolonged the set periods of blended cement paste. C_3A reacts with both water and gypsum, which causes the cement to set. However, paper ash contains less C_3A than OPC, hence it sets cement more slowly. Therefore, the blended cement paste's setting time was delayed by the reduced C_3A content. The Ethiopian standard stipulates that cement must initially set in no less than 45 min and must finish setting in no more than 10 h. The findings for the setting time showed that adding wastepaper ash to the mixture delayed the setting, but this delay was within the parameters provided by the Ethiopian standard [35]. However, research finds that in comparison to control

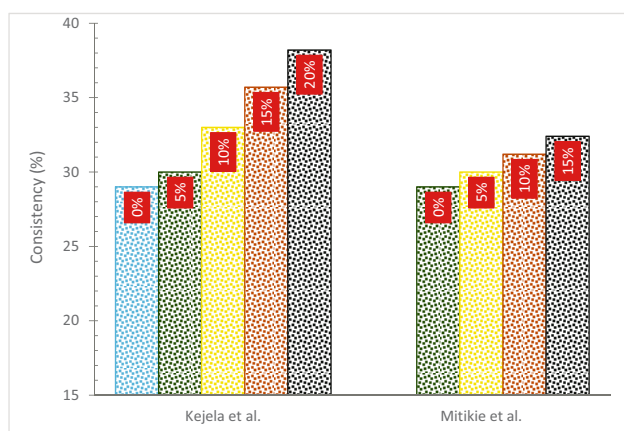


Figure 4: Normal consistency [29,35].

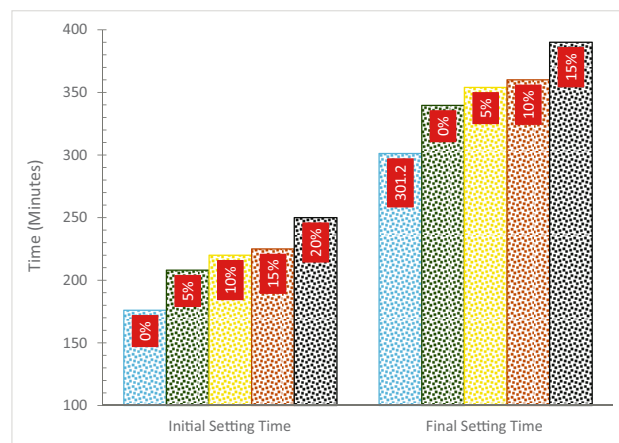


Figure 5: Setting time [35].

concrete, concrete mixture reduces both the start and final setting durations [29]. There might be three causes for this. First, compared to cement, wastepaper pulp ash absorbed more water. The hydration process could be sped up by the high-water absorption of pulp ash particles. As a result, the period of time required to establish was shortened. Second, by increasing the paper pulp ash substitute, the mixture's gypsum content (which is present in the cement) decreased. As a result, quick setup times might happen. Third, the significantly increased CaO level in paper pulp ash may further affect the hydration process.

3.3 Slump

Slump as a function of paper pulp ash is displayed in Figure 6. The slump decreased when more paper pulp content was added. The pulp showed a strong capacity for absorbing water. As a result, additional water was needed to obtain a similar slump and there was a greater proportion of paper pulp in the combination [40]. Similar research found that adding ash from paper pulp reduced slump [41]. Research also found that the slump flow decreased when wheat straw and millet husk ash concentrations increased. With these behaviors, it may be concluded that the geo-polymerization process caused considerable amounts of water to be consumed at greater millet husk ash and wheat straw ash levels due to the microparticle size of these materials. As a result, the composite has a tendency to be thicker, which reduces flowability [42].

A number of things might have a negative impact on how workable paper pulp concrete is. The major causes of the decreased workability of concrete would be the substitution of paper pulp, paper pulp physical characteristics, and paper pulp carbon content. As the paper pulp percentage rises to roughly 20%, the decrease in water requirement becomes greater [40]. The flow test revealed that the flowability of the cement mortars decreased when ash was substituted for 10–30% of the cement [44]. Woody ash's physical properties, such as its irregular particle shape and higher surface area, make it detrimental to concrete's flowability. Since a larger surface area required more cement paste for flowability, little workable concrete was generated. Concrete is becoming less workable as a consequence of increased internal friction between the materials due to uneven shape and larger surface areas. In comparison, other research suggests that adding filler materials to small gaps might contribute to a rise in the slump [45,46]. As a consequence of the reduced voids, there is more cement paste accessible for rheological properties [47]. Paper pulp ash helps to increase the flow of concrete by filling up small gaps; however, since it is permeable, the flow value of concrete is reduced.

4 Strength properties

4.1 Compressive strength (CS)

Compressive strength as a function of paper pulp ash is displayed in Figure 7 and Table 1. Typically, the addition

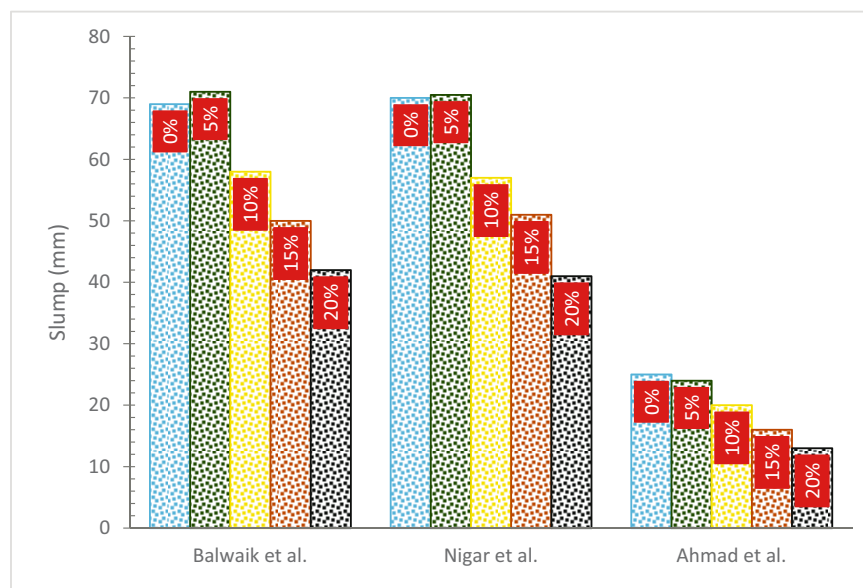


Figure 6: Slump flow [40,41,43].

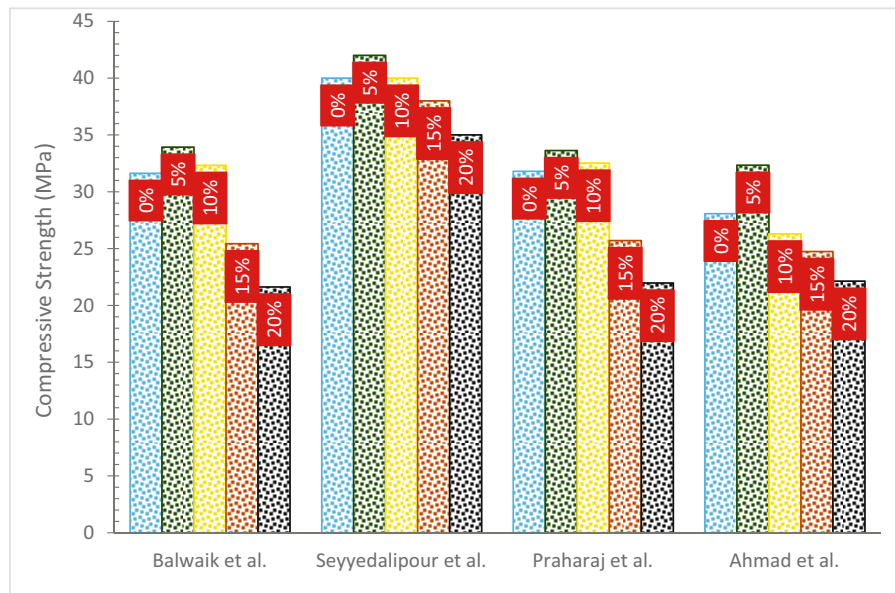


Figure 7: Compressive strength [40,43,48,49].

of wastepaper pulp increases the compressive strength by up to 10%, and subsequent increases in wastepaper pulp progressively diminish the strengths [48]. A study also concludes that when the paper pulp content is increased, the compressive strength of wastepaper pulp-based concrete rises until it reaches 10%, after which it steadily declines [41]. The findings show that at 5% cement substitution with wastepaper sludge ash, the compressive strength increased, beyond that, it started to decline. When concrete using 0% wastepaper sludge ash in lieu of cement was tested, the maximum compressive strength was found to be 15% higher than that of the reference mix at 28 days [43].

Comparing the 28 days compressive strength of the control mix formed with regular Portland cement, an improvement of 5.6 and 1.2% was seen for 5 and 10% substitution. This is because paper ash contains more silica than cement does, which explains why. However, it showed that the amount of cement substitution had a significant impact on how much the strength had improved. It was noticed that the compressive strength of the concretes containing 15 and 20% wastepaper ash had decreased [35]. The compression strength (CS) of cement mortar mixtures including FA from biomass-fired power plants was studied. Cement was replaced at levels of 10, 20, and 30% of the total weight of the binder with FA generated from wood waste. Mortar mixes with a 10% wood waste FA additive demonstrated higher CS at 28 days but lower flexural strength (FS) when compared to identical pure OPC mortar. When wood waste FA was employed as a partial cement replacement

material at higher replacement levels of 20 and 30% of the total binder weight, the CS of the 28 days mortar mix was discovered to be lower [50]. The feasibility of employing wastepaper pulp ash as an alternative material utilized as a partial cement replacement in the production of concrete was investigated, and its impact on the qualities of concrete was looked at. For 25 MPa concrete, four mixes with varying percentages of wastepaper pulp ash in lieu of OPC and paper pulp concrete were created: 0, 5, 10, and 15%. When wastepaper pulp ash was used instead of cement by 5%, the CS increased compared to the control mix (0%).

It was discovered that the concrete mix with paper ash replacements of 10 and 15% had lower compressive strength than the control mix (0%). This may suggest that wastepaper pulp ash has the ability to replace up to 5% of the weight of OPC. The high replacement of cement by wastepaper pulp ash results in a decrease in cement, which in turn leads to a reduction in the hydration process, which results in a loss in compressive strength with the rising substitution of wastepaper pulp ash [29]. Wastepaper contains amorphous silica, which when combined with accessible lime (which forms when cement is hydrated) produces additional cementitious compounds such as calcium silicate hydrates. The key factor contributing to the increase in strength is the calcium silicate hydrate, which strengthened the paste's binding abilities and enhanced the microstructure. However, it showed that the amount of cement substitution had a significant impact on how much the strength had improved. It was noticed that the

Table 1: CS as a function of paper pulp ash

Ref.	Substitution	Substitution range (%)	W/C	Optimum dose (%)	Compression strength (MPa)				CS at optimum %	Remarks
[40]	Cement in concrete	0	0.5	5	14 days	28 days			14 days = 16.2	Compressive strength increased
		5			22.04	31.63				
		10			25.62	33.93				
		15			23.53	32.33			28 days = 7.27	
		20			18.85	25.43				
[48]	Cement in concrete	0	—	5	16.72	21.62				Compressive strength increased
		5			28 days				28 days = 5.0	
		10			40					
		15			42					
		20			40					
[41]	Cement in concrete	0	—	5	38					Compressive strength increased
		5			35					
		10			14 days	28 days			14 days = 12.88	
		15			22.5	31.8				
		20			25.4	33.63			28 days = 5.75	
[51]	Cement in mortar	0	—	5	23.13	32.53				Compressive strength decreased
		5			19.1	25.7				
		10			17.05	21.97				
		15			7 days	28 days	56 days	90 days	7 days = 2.85	
		20			21	31.9	33.5	33.8	28 days = 2.82	
[25]	Cement in composite	88	—	80	20.4	31	33.4	33.1	56 days = 0.29	Compressive strength increased
		86			19.8	30.9	32.6	32.3	90 days = 2.07	
		84			18.7	27.6	31.3	30.9		
		82			16.5	26.2	29.5	30.3		
		80			28 days				28 days = 175.0	
[34]	Cement in composite	75	—	70	2					Compressive strength increased
		70			2.5					
		65			3					
		60			3.5					
		55			5.5					
[43]	Cement in concrete	0	0.45	5	3					Compressive strength increased
		5			3.2					
		10			3.8					
		15			28 days				28 days = 144.4	
		20			45					
[20]	Cement in concrete	0	0.4	5	125					Compressive strength increased
		2.50			55					
		5.00			135					
		7.50			90					
		10			110					
[43]	Cement in concrete	0	0.45	5	75					Compressive strength increased
		5			100					
		10			7 days	28 days			7 days = 10.00	
		15			21.48	28.07				
		20			23.62	32.34			28 days = 15.21	
[20]	Cement in concrete	0	0.4	5	20.15	26.29				Compressive strength increased
		2.50			17.92	24.74				
		5.00			15.14	22.14				
		7.50			28 days				28 days = 18.55	
		10			20.1					
[20]	Cement in concrete	0	0.4	5	16.37					Compressive strength increased
		2.50			24.12					
		5.00			23.53					
		7.50			32.36					
		10								

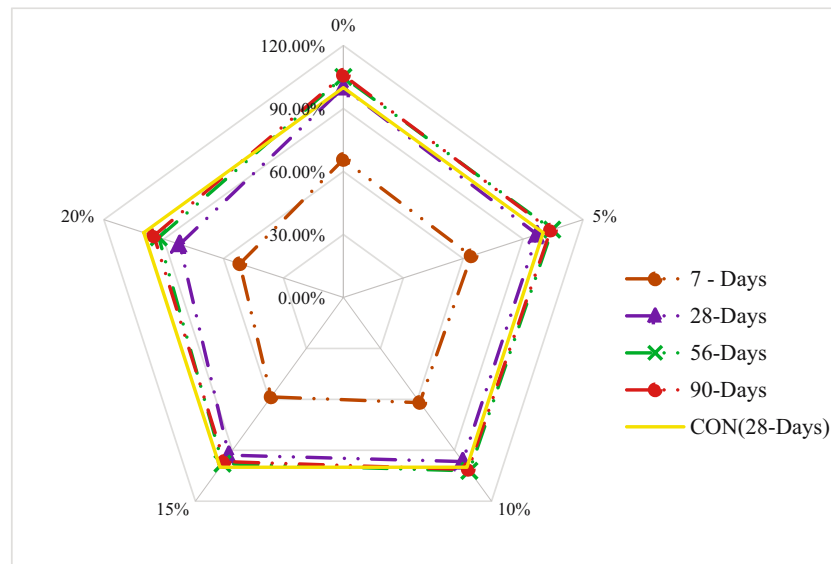


Figure 8: Relative compressive strength [51].

compressive strength of the concretes containing 15 and 20% wastepaper ash had decreased [35]. Additionally, it has been said that using cementitious materials at the proper dosage would enhance efficiency [47]. The greater the cementitious material dosage, the lower the strength qualities of the concrete owing to the dilution effect, which causes alkali–silica reactions. Furthermore, when the filler content of the composite grows, the matrix gets thicker, which strengthens the composite and allows it to bear stress more effectively. However, at greater concentrations, the filler is unable to properly mix with the matrix,

resulting in phase separation of the continuous and scattered phases.

Compressive strength as a function of different paper pulp concentrations and curing durations is shown in Figure 8. After a period of 28 days, the standard strength was taken as a benchmark (control or reference concrete compressive strength). The blend with the optimal amount of paper pulp, which was determined to be 5%, served as a reference standard against which other mixtures containing varied levels of paper pulp were evaluated.

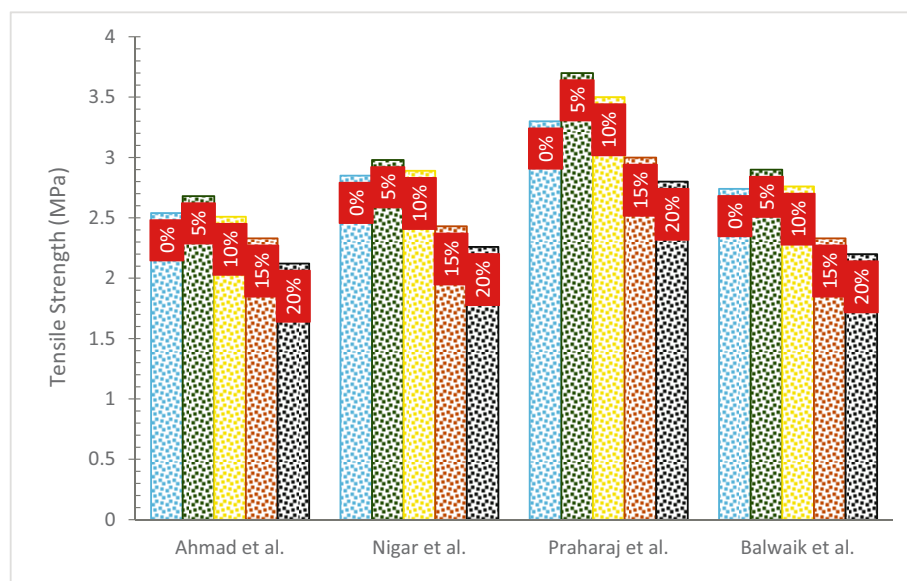


Figure 9: Tensile strength [40,41,43,49].

When paper pulp is used in lieu of cement at a replacement rate of 5%, the compressive strength is reduced by 36% in comparison to the reference strength (28 days control strength) after 7 days but is reduced by just 3% after 28 days. However, after 56 and 90 days of curing, the compressive strength is 4% higher than the standard strength with only 5% of the paper pulp ash being replaced. Additionally, it can also be observed that at 90 days of curing, the compressive strength of concrete is almost equal to the reference concrete. This is due to the fact that the pozzolanic process proceeds at a much slower pace than the cement hydration process [52,53]. There is a possibility that pozzolanic materials have a reduced early-age strength. Similar studies came to the same result that the addition of pozzolanic compounds to concrete enhanced the strength of the concrete as it aged (beyond 28 days) [54].

4.2 Tensile strength

Tensile strength as a function of paper pulp ash is displayed in Figure 9 and Table 2. In general, the tensile strength increased up to 10% in addition to wastepaper pulp and a further rise in wastepaper pulp progressively diminishes the strength [48]. In comparison to the reference mix, the mixture with a 10% addition of wastepaper had a greater splitting tensile strength, which decreased as the wastepaper concentration further increased. In comparison to the control combination, the splitting tensile strength generally improved for concrete mixes including 5 and 10% wastepaper but decreased with a 15% addition of wastepaper [55]. Similar research works reported that adding wheat straw ash increased the material's tensile strength [56]. The tensile strength of concrete mixes including sawdust ash as a partial replacement for cement was

Table 2: Tensile strength as a function of paper pulp ash

Ref.	Substitution	Substitution range (%)	W/C	Optimum %	Tensile strength (MPa)		Tensile strength at optimum %	Remarks
[40]	Cement in concrete	0	0.5	5	28 days		28 days = 5.83	Tensile strength increased
		5			2.74			
		10			2.9			
		15			2.76			
		20			2.33			
[48]	Cement in concrete	0	—	5	28 days		28 days = 12.12	Tensile strength increased
		5			3.3			
		10			3.7			
		15			3.5			
		20			3			
[41]	Cement in concrete	0	—	5	28 days		28 days = 4.56	Tensile strength increased
		5			2.85			
		10			2.98			
		15			2.89			
		20			2.43			
[43]	Cement in concrete	0	0.45	5	7 days	28 days	7 days = 4.71 28 days = 5.51	Tensile strength increased
		5			2.122	2.546		
		10			2.225	2.688		
		15			2.157	2.51		
		20			2.051	2.334		
[20]	Cement in concrete	0	0.4	5	28 days		28 days = 9.72	Tensile strength decreased
		2.50			2.88			
		5.00			2.6			
		7.50			3.16			
		10			3.07			
					3.66			

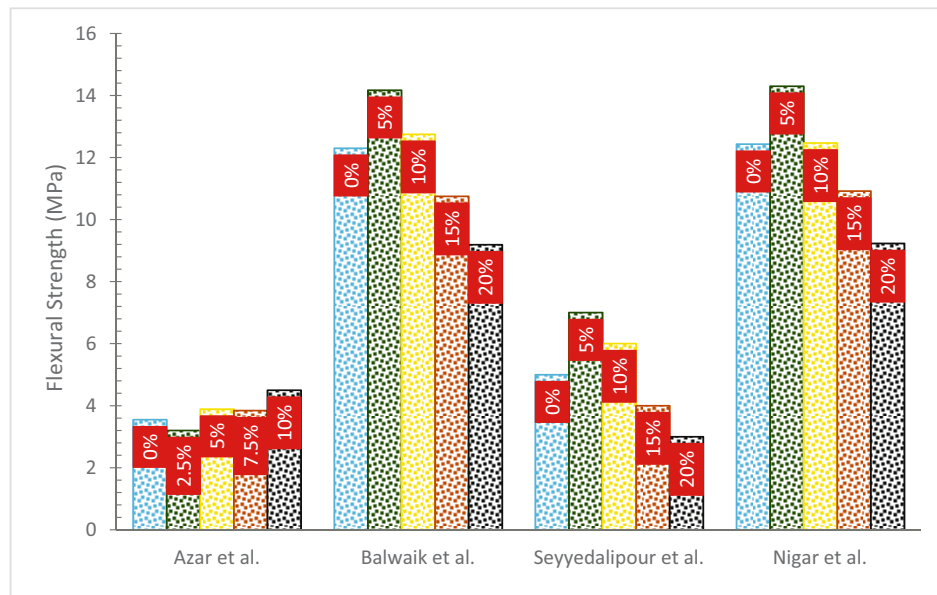


Figure 10: Flexural strength [20,40,41,48].

investigated at 7 and 28 days. A loss in tensile strength with an increase in saw dust ash percentage, but it was not as clear as a drop in compressive strength. After 7 days, it was seen that the difference in strength between the blended cement concrete and control mixtures increased. After 28 days, blended cement concrete mixes with replacement percentages of up to 25% had tensile capacity of up to 90% of the control mixtures' strength [57].

A researcher examined the impact of hardwood ash on the tensile capacity of concrete when it was used as a cement replacement in the production of concrete. 5, 8, and 12% substitution rate of wooden ash were used. The same reference concrete was again poured, but without any wood ash, for comparison. The tensile strength of the constructed concrete samples was evaluated after 3, 7, 28, 91, 182, and 365 days. From the study of the laboratory data, it was determined that the tensile capacity of the control concrete was 3.8 MPa at 28 days and 4.3 MPa after 365 days. The tensile capacity of concrete mixes including wood ash ranged from 3.6–4.0 MPa at 28 days to 4.3–5.3 MPa at 365 days. The concrete with wood ash of 8% was also found to have the best tensile strength development behavior for concrete ages of more than 28 days up to 365 days, with a magnitude of tensile capacity that consistently beat that of other test mixes [58]. The greatest value was discovered at a dosage of 10% wheat straw ash when comparing the tensile strength of wheat straw ash with that of the reference sample. However, when the dosage was raised by more than 10%, the tensile strength

was reduced. The process of compaction becomes more challenging at higher doses (20% of wheat straw ash), although it is still achievable but for the lack of workability that results in more holes and less structural load capability [59]. The continuous and scattered phases separate as the filler's ability to completely mix with the matrix is reduced at greater concentrations. As a consequence, composite materials that include more than 40% paper pulp lose some of their durability [49].

4.3 Flexural strength (FS)

Flexural strength (FS) as a function of paper pulp ash is displayed in Figure 10 and Table 3. In general, the waste paper pulp may boost FS by up to 10%, and subsequent increases in waste paper pulp progressively diminish the strengths [48]. The research found that adding 10 and 15% more waste paper to concrete decreased its FS, however adding 5% more waste paper to concrete increased its FS compared to the control combination [60]. The result showed that high paper pulp levels in concrete mixes reduced FS. The FS of the concrete mixture dropped as the paper pulp percentage increased. The paper pulp content in the concrete mixture had a major effect on the mechanical characteristics of the mixture. The results showed that, usually, the flexural strength increased with additions of the waste paper pulp of 5 and 10%, and that a further rise in waste paper pulp progressively decreased the strength [48].

Table 3: Flexural strength as a function of paper pulp ash

Ref.	Substitution	Substitution range (%)	W/C	Optimum %	Flexure strength (MPa)	Flexural strength at optimum %	Remarks
[40]	Cement in concrete	0 5 10 15 20	0.5	5	28 days 12.3 14.17 12.75 10.75 9.19	28 days = 15.20	Flexural strength increased
[48]	Cement in concrete	0 5 10 15 20	—	10	28 days 5 7 6 4 3	28 days = 40	Flexural strength increased
[41]	Cement in concrete	0 5 10 15 20	—	5	28 days 12.43 14.3 12.74 10.92 9.23	28 days = 15.04	Flexural strength increased
[51]	Cement in mortar	0 5 10 15 20	—	5	28 days 0.22 0.28 0.26 0.19 0.18	28 days = 27.27	Flexural strength increased
[20]	Cement in concrete	0 2.50 5.00 7.50 10	0.4	5	28 days 3.55 3.2 3.89 3.84 4.5	28 days = 9.57	Flexural strength decreased

The adhesion connection between water molecules and the structure of the paper may be used to explain these findings. Adhesion, which may be advantageous to water, is the attraction of one molecule to another molecule of a different particle type. Paper ash has more silica than cement. When the accessible lime and crystalline silica in wastepaper combine to generate cement, new cementitious compounds like calcium silicate hydrates are produced. The key factor contributing to the increase in strength is the calcium silicate hydrate, which strengthened the paste's binding abilities and enhanced the micro-structure [61–64]. However, it showed that the amount of cement substitution had a significant impact on how much the strength had improved. It was noticed that the compressive strength of the concretes containing 15 and 20% wastepaper ash had decreased [35]. It has also been noted that the right optimal dosage of cementitious materials is critical for improved performance [47,65–67]. The dilution effect, which causes alkali-silica reactions,

was responsible for the reduction in the strength qualities of the concrete as a result of the increased dosage of cementitious materials. In addition to this, raising the filler percentage in a composite material causes the matrix to grow denser over time, which in turn makes the composite material more robust and better able to resist the effects of stress. However, when the filler is present in a larger concentration, it is no longer able to combine completely with the matrix, which results in the phase separation of the continuous phase and the scattered phase. In light of the findings presented above, the review suggests using 10% ash from the paper pulp in concrete without causing any harmful effects on the strength attributes of the concrete.

4.4 Impact strength

The capacity of concrete to endure repeated impacts and absorb energy without suffering damage in the form of

cracking or spalling is termed impact resistance. The impact resistance as a function of paper pulp ash is displayed in Figure 11.

The addition of paper pulp results in an increased impact value. This is due to the fact that the paper pulp serves both as a filler and a reinforcing fiber. Studies reported that fiber improved concrete performance due to bridging effects [68,69]. This provides the matrix phase with a strengthening effect, which in turn improves all of the mechanical characteristics, including the impact strength. Thus, when a force is applied, composite materials do not readily fracture. The filler particles, however, become concentrated in one area as the filler concentration rises and are unable to properly mix with the matrix phase. This agglomeration causes phase separation, which progressively degrades the mechanical characteristics above a composition of 40%. As long as the amount of paper pulp is raised, this degradation will continue [49]. According to research, activated FA concrete has superior impact resistance than other mixtures at replacement levels of 10 and 15%. Due to the pozzolanic effect, higher impact resistance obtained in concrete with 10 and 15% FA replacement may be related to decreased permeability [70]. The concrete mixes' fine aggregates were replaced in part by 0, 20, 40, and 60% rubber by volume, while the cement was substituted with 0, 5, and 10% SF by mass. Findings show that the impact energy of rubberized concrete was 2.39 times more than that of regular concrete and that its ability to absorb energy was 9.46% greater. Although SF was added, the impact energy increased by 3.06 times, but the energy absorption capacity remained relatively the same [71]. According to research, SF was added to natural pozzolan-based cement concrete to make up for the early-life compressive strength drop [72]. In spite of

this, the review finds that adding paper pulp increases impact resistance. This is due to the paper pulp's dual roles as a filler and a strengthening fiber, which strengthens the matrix phase and enhances all structural qualities, especially impact strength.

5 Cost benefits

Figure 12 shows the cost reduction of the mix with partial substitution of wastepaper with respect to the reference mix. The optimal proportion of wastepaper was selected for comparison. Since wastepaper pulp ash is a byproduct, the cost is minimal. The cost comparison shows that adding wastepaper pulp ash lowers the price of concrete. Thus, it has been determined that using wastepaper in concrete may, to some degree, reduce disposal costs and generate greener concrete for building. Finally, it was discovered that, when compared to control concrete, the concrete mix with 5% partial replacement of wastepaper pulp ash for cement lowers the cost of concrete by 2.34% while maintaining concrete properties like consistency, workability, compressive strength, absorption, and resistance to 2% sulfuric acid solution [29]. The research was conducted on the economics of bacterial SF concrete [73]. The benefit/cost ratio of SF concrete decreased as the SF amount increased. In contrast to the reference blend, SF concrete with 10% SF displayed the greatest advantage in terms of property improvement and the highest benefit/cost ratio. According to one research, using pozzolanic elements in concrete may increase concrete durability, setting time, and cause fewer energy releases, and costs linked with structural preservation and restoration throughout the structure's planned service life. Furthermore,

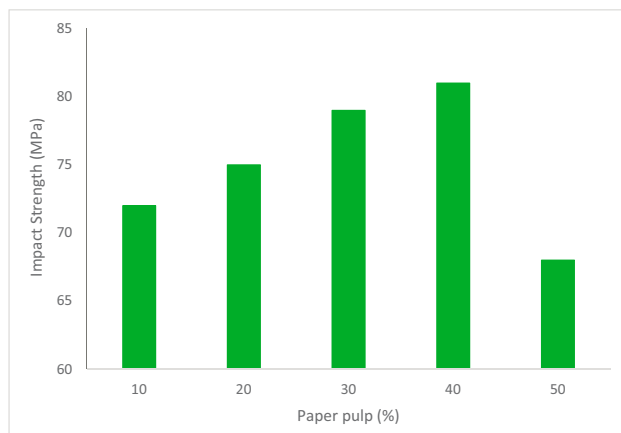


Figure 11: Impact strength [49].

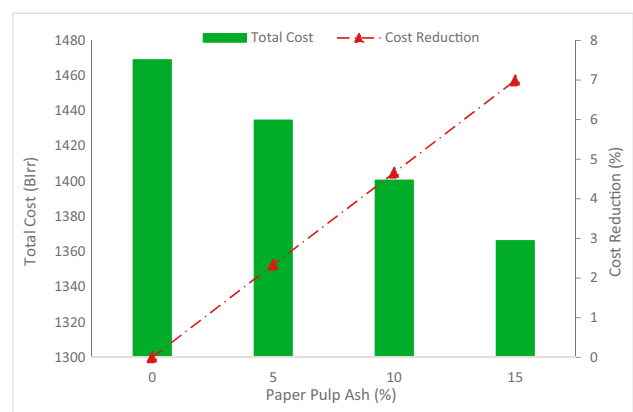


Figure 12: Cost benefits of paper pulp in concrete [29].

even at the greatest distance FA can be delivered for concrete, including FA to provide ecological and financial advantages over concrete without the presence of FA [74].

6 Environmental benefits

Due to the significant consumption of resources by never ending building projects, environmental consequences from the cement and concrete industry have raised concerns around the globe [75–78]. The removal of raw materials to the dismantling of a concrete structure is only a few of the many steps in the process of building with concrete that pose significant sustainability challenges [79–82]. Recycling leftover concrete from construction and demolition debris (waste), rerouting the life cycles of essential components, and lowering the amount of solid trash disposed are all becoming more important as the world transitions to a more sustainable lifestyle [83]. Diverse waste types are becoming more often generated in a range of quantities and standards. In order to preserve and safeguard human health in metropolitan populations and to boost systematic productive capacity at all levels of waste disposal, it has become vital to use modern solid sustainability practices to build successful strategies for collection, transportation, and processing technologies [20].

The incineration of discarded paper affects the surrounding environment since it results in the emission of air pollutants into the atmosphere. When burned, printed paper releases a much greater quantity of air pollutants than unprinted paper does. This may be the result of the printing ink releasing additional pollutants into the air, such as carbon dioxide and nitrogen oxides. In addition, heavy elements including lead (Pb) and cadmium (Cd) were discovered on the ash of burnt papers, which suggested that the ash may be combined with the soil. Heavy metals such as lead, and cadmium are examples of hazardous heavy metals that may have an adverse impact on human health. They have a negative impact on the central and peripheral neurological systems, as well as the kidneys, and they contribute to the inhibition of production of hemoglobin. Pb also has an impact on the kidneys. Cd has a deleterious effect on several essential enzymes and has also been linked to osteocalcin, a painful bone condition, and found to cause harm to the kidneys. Cadmium pneumonitis is caused by the inhalation of cadmium oxide dust and fumes, and its symptoms include pulmonary necrosis of the pulmonary epithelium. In addition, two more advantages come with using recycled paper for

cement in construction. The first advantage is that it helps maintain the quality of the surrounding environment, and the second is that it may be utilized in the manufacturing of concrete as an alternative to cement. According to the findings of the research, there are two positive aspects associated with using recycled paper in place of cement. The first advantage is that it helps to preserve the quality of the environment, and the second is that it may be substituted for cement in the production of concrete [29]. In addition, the manufacture of cement is a contributor to environmental degradation since it results in the release of hazardous gases.

7 Conclusion

This article provides overview of green construction ideas that deal with making the most of resources that are often wasted (paper pulp ash). The majority of the attention was placed on how they influenced the qualities of the construction material, the appropriate composition of the mixture, and a discussion of the benefits and drawbacks of the “green” addition (paper pulp ash). The focus of this study is on concrete’s essential properties, which include consistency, setting time, flowability, compressive, flexural, tensile, and impact strengths. In addition, the benefits of employing paper pulp ash as construction materials are examined from both an economic and ecological standpoint. The comprehensive findings are provided below.

- The normal consistency of concrete raised slightly with the incorporation of paper pulp ash due to the porous nature of paper pulp which required more water to obtain normal consistency.
- An increase in setting time was observed with the substitution of paper pulp ash. It is due to the larger quantity of CaO present in paper pulp ash, which accelerated the setting of paste.
- The flowability of concrete declined with the incorporation of paper pulp ash due to its strong capacity for absorbing water. Therefore, additional water was needed to obtain a similar slump.
- The strength properties of concrete such as compressive, flexural, tensile, and impact strengths increased with the incorporation of paper pulp ash. The increase in strength properties is mainly due to micro-filling voids of paper pulp ash. Furthermore, the optimum amount is valuable as the greater dose negatively impacts the strength properties due to a lack of flowability. Therefore, the review recommends to a used optimum dose of paper pulp ash. The typical optimum dose of paper pulp varies from 5 to

10% depending on the mix design, chemical composition, and particle size.

- The cost–benefit study reveals that the concrete mix with 5% of wastepaper pulp ash as cement lowers the cost of concrete by 2.34% while maintaining equal consistency, workability, and strength qualities as compared to reference blends.

8 Recommendations

Although paper pulp ash may be used in concrete to a certain level (5–10%), a more thorough investigation is required before it can be used practically.

- The normal consistency and flow of the concrete decreased with paper pulp due to the porous nature of paper pulp ash which adversely affects the concrete performance. Therefore, the review recommends a detailed study of the different treatments of paper pulp ash to be used in concrete to avoid its unfavorable effects (water absorption).
- Many researchers claim that particle size significantly influences the strength properties. Therefore, the review recommends a detailed study on the particle size effect of paper pulp ash on concrete properties.
- There is no information about concrete incorporating paper pulp ash in a aggressive environment. Therefore, more study in this area is needed.
- To improve the ductility of paper pulp ash concrete, the review also recommended the addition of fiber to obtain high-strength ductile durable concrete.

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