OPEN ACCESS

Kashf Journal of Multidisciplinary Research
Vol: 03 - Issue 01 (2026)
P-ISSN: 3007-1992 E-ISSN: 3007-200X
https://kjmr.com.pk

IMPACT ANALYSIS OF WASTE UTILIZATION ON MECHANICAL PROPERTIES OF SUSTAINABLE GREEN MATERIALS

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DOI:(*https://doi.org/10.71146/kjmr799*)

Article Info

Abstract

Sustainable symmetric green materials are very important for large civil engineering projects. Predominantly, when Bio-waste materials are used in materials to improve strength and other related properties. This process helps to eliminate the environmental hazard and contribute to the low carbon production of traditional materials such as fine aggregates and cement where the sources are rare and expensive. This manuscript presents the utilization of waste products to study their individual filler effect on concrete. Waste material like Paper Sludge (PS) has been used in this research study. These materials were added as partial replacement of 3%, 6%, 9%, 12 % and 15% with binder. The concrete performance was analyzed based on mechanical characteristics such as with reference to binder replacement at the end of 7- and 28-days curing conditions. Control samples were prepared to compare the results with those that contained PS. The results obtained, revealed that waste materials can serve as replacement to maintain the mechanical properties of sustainable concrete. This study will help in the mass production of concrete with the help of waste materials resulting in eco-friendly economical sustainable infrastructure development especially in less load bearing structures.

Keywords:

Circular Economy; Polymer waste; Waste material; Performance; Sustainability.

1. Introduction

The concrete sector is one of the biggest customers of natural virgin materials such as sand, aggregates, and cement. The construction industry is growing rapidly in developed countries[1]. Therefore, there is a need to find alternative materials due to a shortage of natural materials such as sand and aggregates [2]. The worldwide cement sector adds to the atmosphere of the earth about 7 percent of greenhouse gas emissions. Therefore, researchers are now searching for alternative building materials as a replacement for traditional materials such as cement, sand, bricks, tiles, and aggregates to reduce environmental hazards. One of the best strategies is to use waste products rather than natural resources in order to make the concrete industry sustainable which also improves the strength of normal sustainable concrete. Therefore, there is a need to do more research to find out the industrial by-product as a substitute for cement or sand as a filler in the manufacturing of concrete. The production of solid waste from paper industries has become the source of environment concern [3]. In order to meet the tremendous demand from the concrete construction industry, an acceptable environmentally friendly alternative to sand must be sought. The recycled plastic can save 820 million tons of sand annually by replacing 10% sand [4].

Fillers are materials that are mainly based on size and shape in concrete. They interact with cement in numerous ways; improve the packaging of particles and bring other properties to the fresh concrete, and even reduce the amount of cement in concrete without compromising the strength. Fine material passes through 0.063 mm sieve called filler according to the European standard. They found that the maximum strength of compressive and flexural was achieved at 55 % when recycled aggregates are used as a substitute to sand [5]. Cordeiro et al have published a paper defining filler as inactive materials that rely primarily on the particle size, shape, texture of that material. A finer particle can fill the gap between the cement paste or concrete that significantly improves the properties of cement paste or concrete [6]. The filler is either pozzolanic or non-reactive materials that enhance granular filling factor and luck-up capillary pores in the concrete mix[7, 8]. Many studies have been done both in past and ongoing in order to understand the effect of utilizing several industrial wastes (fly ash, silica fume, limestone, marble dust, rice husk ash, palm oil fuel ash)[9-18] in composites. It is more essential to understand its dual effect both filler and pozzolanic effect when reactive by-products are used as filler in concrete or other construction purposes [6, 9, 11, 19-22].

Several experiments have been reported to distinguish between the filler and pozzolanic effect by incorporating reactive with non-reactive materials [10, 11, 20],this indicates that when reactive (pozzolanic) materials are used as a substitute to fine aggregate or cement it gives two effects; they fill the internal voids as a filler and being pozzolanic in nature they react with cement to enhance the strength-related properties of concrete or mortar. In this study, the potential use of waste products as a filler material such as Alum sludge and paper sludge in the production of concrete. The previous studies show that most of the filler material is considered to have both filler and pozzolanic effects, while others have little or no reaction to the hydration of concrete. Waste paper sludge could be successfully used as a substitute in the concrete mix because it behaves like cement due to its silica and magnesium properties [23]. They carried out a split tensile test on M20 and M30 mixes. It was noted that tensile strength is elevated with the utilizing of paper sludge up to 30% by weight of cement beyond that limit it tended to decrease [24]. Paper sludge could be feasible to use an alternative material to fine aggregate in making concrete and also to reduce the cost [25].

Finally, the circular economy is a comprehensive concept for our economy aimed at keeping products and materials as long as possible. Although scientists face additional challenges in research, technologies and infrastructure, these are individual dissertations that provide a humble contribution to this modern subject. From this it can be concluded that in addition to investing in disseminating information, education and technology, it also needs to develop and strengthen the business potential that applies the concept of circular economy.

Figure 1. Circular Economy Cycle[26]

This study presents the utilization of waste products to understand their individual filler effect and made a detailed comparative analysis when used as a replacement of fine aggregates in the concrete mix. For the first time, virgin waste materials like paper sludge have been utilized as a replacement to sand in this study for the development of sustainable concrete. Utilization of theses material provides efficient and improves strength-related properties of normal concrete and eco-friendly too. This study helps to provide a solution to the disposal problem, thereby reducing environmental hazards.

2. Materials and Methods

2.1 Cement

The basic cementitious material used in this work according to ASTM C-150[27] are Grade 53 of Type-1. The manufacturing company of ordinary Portland cement is Maple Leaf Pvt. Ltd. The physical and chemical properties of cement are shown in Table 1 [28-32].

Table 1. Ordinary Portland Cement Chemical & Physical properties.

ĻOI	ŞiO2	Äl2O3	Ḟe2O3	ÇaO	ṀgO	ŞO3	Ǩ2O	Ńa2O
3.48	20.80	4.97	3.15	63.17	1.86	2.64	0.66	0.42

Property	Unit	Result	Standard
(Density)	Ǩ g/m3	1440	ÄSTM C-188
(Normal Consistency)	% age	28	ÄSTM C-187
(Fineness)	% age	92	ÄSTM C-184
(Initial Setting Time)	min	135	ÄSTM C-191
(Final Setting Time)	min	190	ÄSTM C-191
(Soundness)	mm	1	BS---196-3

Note: BS= British Standard, ASTM= American society for testing and materials

2.2 Fine Aggregate

The fine aggregate with a size <4.75 mm was used & the density of sand is 1540kg/m3. Waste products such as paper sludge were used as a fine aggregate replacement for prepared concrete mix. The gradation curve of fine aggregate was shown in figure 1.

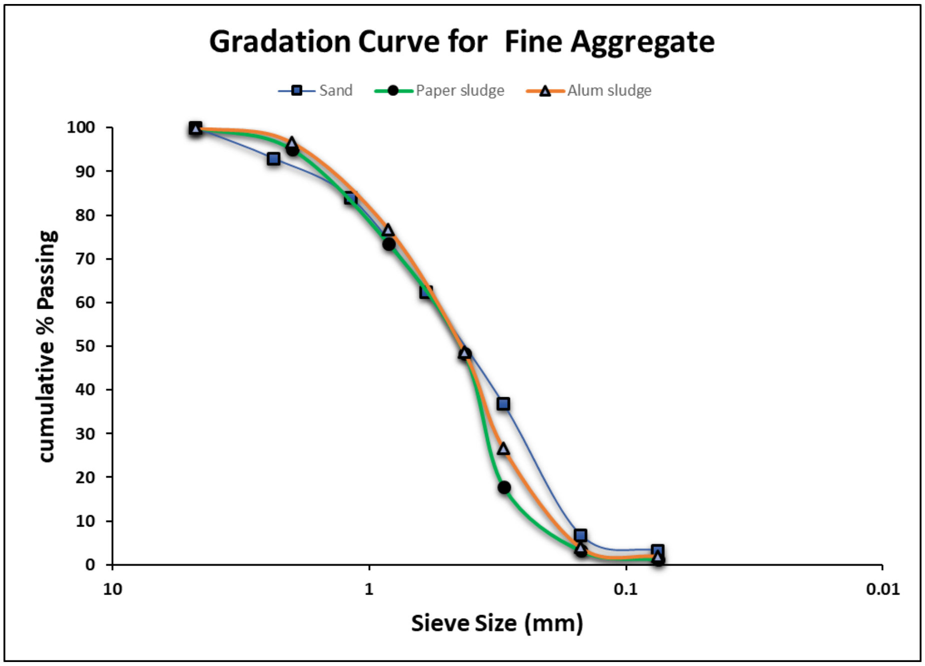

Figure 2. The grain size distribution of fine aggregate (sand) and waste materials used as a sand replacement

2.3 Coarse Aggregates

In this research, one type of crush composed of "Mixed Limestone (55%) and Sandstone (45%) was used and the density is 1510 kg/m3. It was passed through ranges from 10 to 20mm sieve to remove organic impurities. The gradation and detailed physical properties of coarse aggregate performed in the lab were given in Fig 2 and Table.2 respectively.

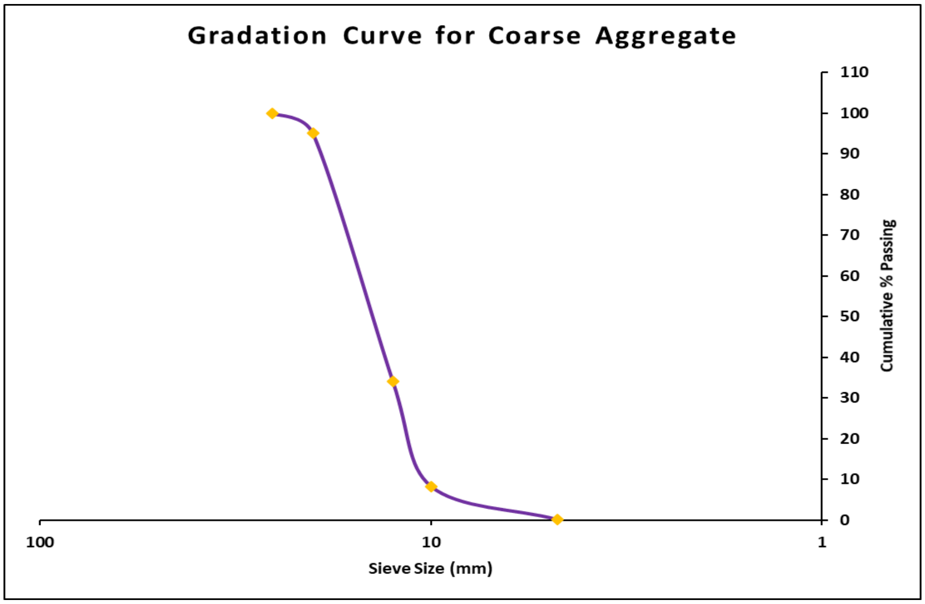

Figure 3. The grain size distribution of coarse aggregate

Table 2. Physical Properties of aggregate

Type of Test	(Standard)	(Result)	(Specs.)
(Agg Impact Test)	BS812: Part3	21.33%	Less than 27%
(Los A. Abrasion Test)	ÄSTM: C131	27%	Less than 35%
(Agg Crushing Test)	BS812: Part3	23.21%	Less than 30%
(Water Abs Test)	ÄSTM: C127	1.90%	Less than 2%
(Sp. Gravity (Agg)	ÄSTM:C127	2.33	2 to 3

Note: BS= British Standard, ASTM= American society for testing and materials

All the values of basic physical tests less than the limits that are mentioned in table 1. Besides, these assessments are identical crucial to known about the quality of coarse aggregates that are utilized in this study.

2.4 Paper Sludge

Paper Sludge is a waste material that generates mass quantities of sludge worldwide and normally disposed to landfill. Thus, created several environmental pollution issues. Paper sludge is mostly composed of cellulose fibers, moisture, and paper-making filler [33]. A huge amount of wastepaper sludge is produced worldwide. In Asian countries, 0.7% of the total urban waste produced consists of paper sludge as there are around about 100 small and medium-sized paper manufacturing industries are working that produced nearly 650-thousand-ton paper annually. The UK generates more than 1.5 million tons of wastepaper sludge per year. Our actual production is only 185.4 ton/annum due to some issues. This amount is inadequate to fulfill the country's domestic requirements. Therefore, Pakistan exports annually around 36.52 thousand tons of paper. Thus, there is a need to install more paper industry to reduce paper imports. This can have adverse environmental impacts. In Pakistan, sludge from paper mills is normally disposed of in open lands. These waste materials generated environmental hazards. During the rainy season, this sludge is carried out through runoff water and ultimately reach in a water body. The Kabul River affects the nature of the river[34].

Papers sludge used in this research was obtained from a local source in Pakistan from the paper manufacturing industry. It was sun-dried for several days and then oven dries at 110° C and kept for 24 hours to remove water content. It was sieved from <4.75mm sieve to be used as fine aggregate with reference to ASTM specifications. The chemical and physical properties shown in Table 4.

Table 4. Chemical and Physical properties of Paper Sludge.

Chemical Analysis (%)									
SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	P_2O_5	LOI
26.34	12.67	1.25	29.12	1.49	0.51	0.69	0.56	0.18	19.07

Physical Properties		
Property	**Unit**	**Results**
Specific Gravity	____	2.71
Moisture Content	%	6.23

2.5 Preparation of Concrete

Different experiments have been done carefully to investigate the hardened properties as well as the fresh properties of paper Sludge modified concrete. It was prepared like ordinary concrete with 3%,6%,9%,12% and 15% replacement of fine aggregate by weight. The mix design was used for the concrete mix design of M15 with a W/C ratio of 0.65. All samples were prepared and placed in a curing tank for 7- and 28-days curing age. After then, mechanical properties are testing with the help of a compression machine available in the concrete lab. The Mechanical tests were carefully performed on the casted sample to obtained optimum strength by served the waste material at different percentage levels. The mixing proportion is shown in table 3 for the casted sample of modified concrete by paper sludge.

Table 5. Mix Design for the Development of Concrete

Mix ID	Cement	Paper Sludge	Fine Aggregate	Coarse Aggregate	Water
	kg/m^3	kg/m^3	kg/m3	kg/m^3	kg/m^3
CC 0%	317	0	669	1312	206
PS3%	297	20	669	1312	206
PS6%	277	40	669	1312	206
PS9%	257	60	669	1312	206
PS12%	237	80	669	1312	206
PS15%	217	100	669	1312	206

3. Results and Analysis

3.1 Properties of Fresh Concrete

The consistency and workability of fresh concrete were evaluated by the slump cone test before casting. It was performed both in the laboratory or the construction site. This test plays a vital role in assessing concrete quality at the construction site or on a concrete lab. Due to low cost and immediate results this test is used worldwide and performed according to ASTM standards [35]. In this study, a standard slump cone was used to evaluate the quality of the prepared concrete mix. The slump cone was usually filled in three layers and 25 stokes are applied with the help of rod (16 mm diameter) on each layer to eliminate air voids. The top surface of the concrete was cut off. The height of the slump was measured when the cone is removed and then results were compared with the standards founds in literature[36]. The results of the slump cone are shown in fig 3 with added paper sludge (PS) in concrete.

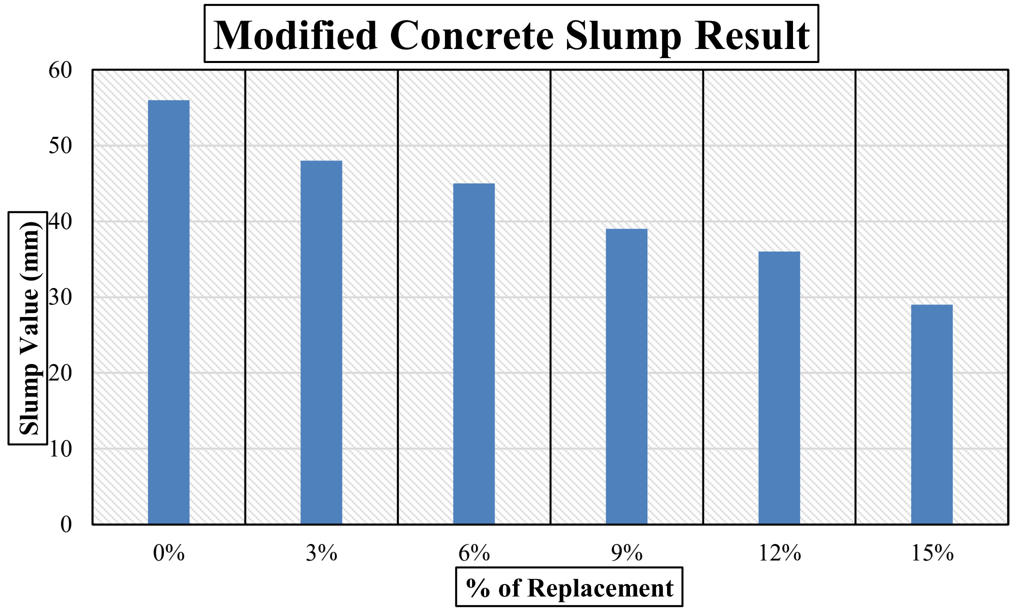

Figure 3. **Slump Test Analysis**

The results indicate that true slump was obtained for all prepared mixes, regardless of the percentage replacement. The higher the percentage of fine aggregates replaced by both materials; the less concrete workability as shown in fig.3.

3.2 Properties of Hardened Concrete

Durability, performance, and corrosion resistant nature of concrete could be assessed by their mechanical properties which are investigated by compression testing machines [37]. The mechanical properties are known for concrete behavior under different loading conditions. Such properties are largely influenced by the type of materials used, aggregates size, composition and water-cement ratio of the mix. The high degree of durability and increased strength could be achieved by using paper sludge as a substitute to binder. To analyze concrete behavior, strength test like compression test is performed.

In the compression test, the load is applied gradually until the sample fails. For this purpose, the cylinder (6'' x 12'') is cast by both materials. Due to compression load, cylinder specimens undergo lateral expansion and eventually split along its full length. The conceptual formation has been shown in Fig.4. Concrete performance can be determined by using these types of tests.

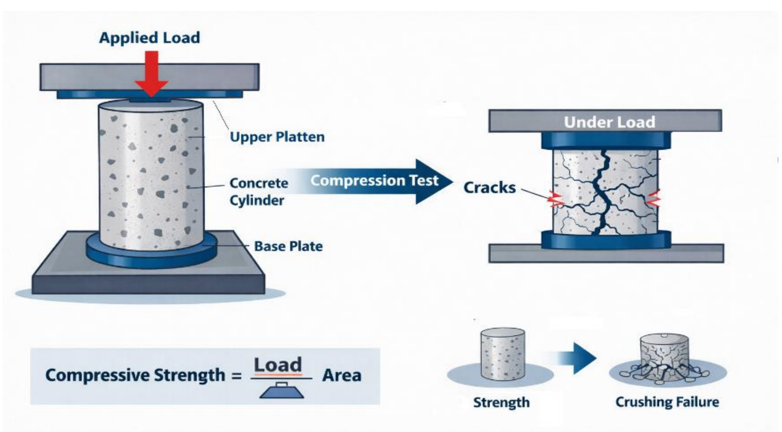

Figure 4. Mechanisms of Compression Test

3.2.1 Compressive Strength (7 Days)

Three samples were prepared and tested for six ratios with P.S materials for the evaluation of their compressive strength. The cylinder was crushed after 7 days of curing age. A control sample was prepared for a detailed comparative analysis of sludge concrete. For each % binder substitution, the optimum percentage was found. From the results, as shown in fig 5, it is indicated that PS as suitable option.

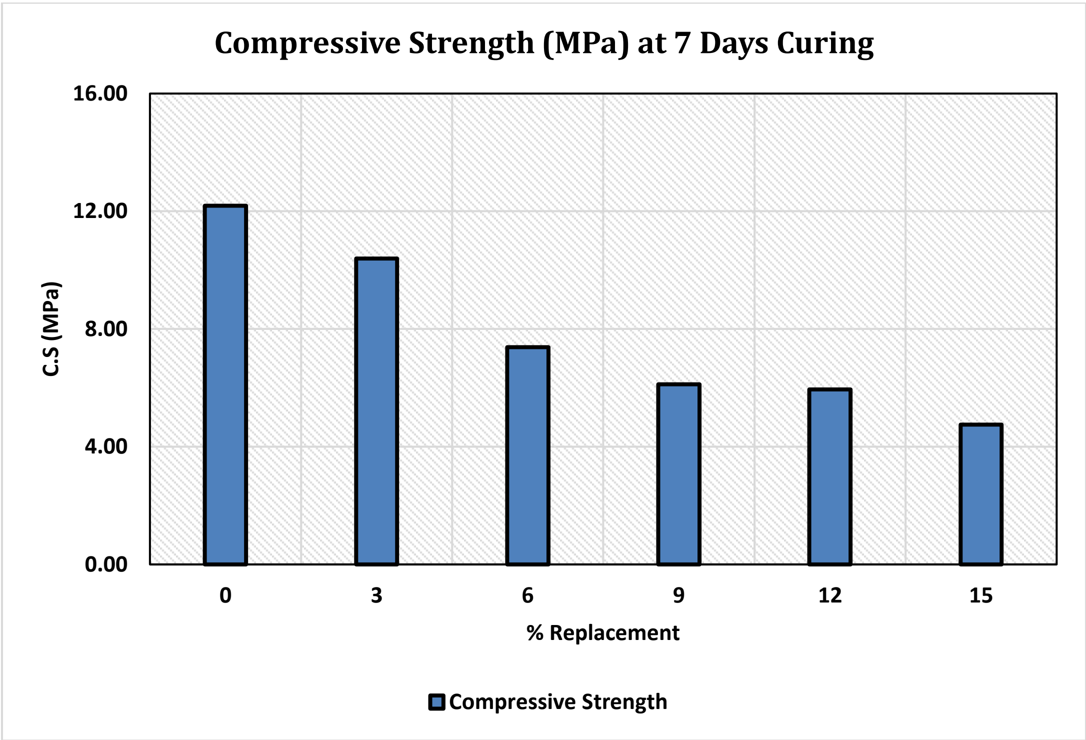

Figure 5. The compressive strength (7 days) of concretes with the % replacement of paper sludge

The key fact about the PS based concrete can be suitable option where concrete is just a filler material. The amount of these essentials is very high relate to cement & paper sludge clearly shown in table 3. At 3% binder replacement with P.S stretches almost equal strength in this study shown in figure 5.

3.2.2 Compressive Strength (28 Days)

Three samples were prepared and tested for six ratios with P.S materials for the evaluation of their compressive strength. The cylinder was crushed after 28 days of curing age. A control sample was prepared for a detailed comparative analysis of sludge concrete. For each % binder substitution, the optimum percentage was found. From the results, as shown in fig 6, it is indicated that PS as suitable option.

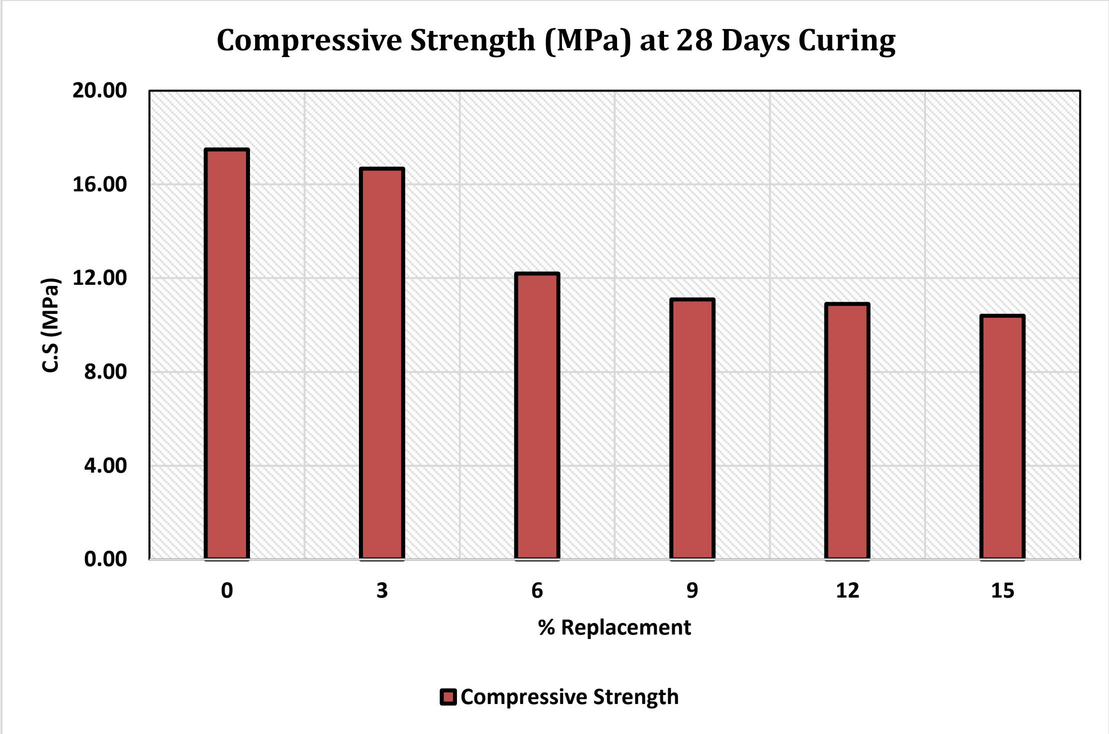

Figure 6. The compressive strength (28 days) of concretes with the % replacement of paper sludge

4. Recycling for Construction: An opportuity towards Circular Ecoonomy

Any manufacturing process should be designed to produce minimal waste and have a low climate effect. The sort of raw materials utilized in the manufacturing process, as well as waste management, are important factors in determining the climate footprint. The collecting of waste is the initial step in the recycling of waste materials. Industries, major companies, and municipal governments can gather all waste debris directly. In recent times, roadside drop-off, repurchase, and deposit or refund systems have been used to collect paper waste and cardboard boxes from the public. After gathering, separating such products, it is a vital operation in which the waste is sorted according to its class and kind, as well as the availability of different pollutants. To separate different types of wastes, hand, and automated processes (dry screening, air sorting, electrostatic sorting, and mechanical sorting) have been utilized. To prevent the existence of extraneous materials, the processed residues are cut into pieces and washed. Different materials have been used in previous literatures and was implemented already in construction industry. In most cases, polymer-based materials research leads to enhanced fatigue and plastic deformation properties. Furthermore, such sort of modifiers is more resistant to adverse conditions. The absence of commercial recycling plants that can quickly process a given product into settings that are suitable for its integration into binder, according to the researchers, is one of the causes why this type of product has not been widely used as an additive material. The answer is to move even closer to a circular economy, in which plastics are recycled, recovered, and created from renewable resources. According to circular model (Figure 7), there is a need to boost waste circularity through engaging with companies to improve recycling process and improving the Organization's own recycling capacities and continuous efforts have made to engage with other participants in the waste product lifecycle about the circular economy. Different industries have started process of recycling. Based on case studies released, the recycling procedure could utilize waste products from can save CO_2 emission and improve use of waste under sustainability and manufacturing concept[38]. Hence, the incorporation of such waste materials in making infrastructures helps to reduce the environmental effects (by reducing production of CO_2) as well as comply with circular economy model which helps to reduce this waste. In addition, the use of waste materials as a modifier in construction gives an opportunity to reduce the overall cost of binder and also ensure sustainable practice through circular economy.

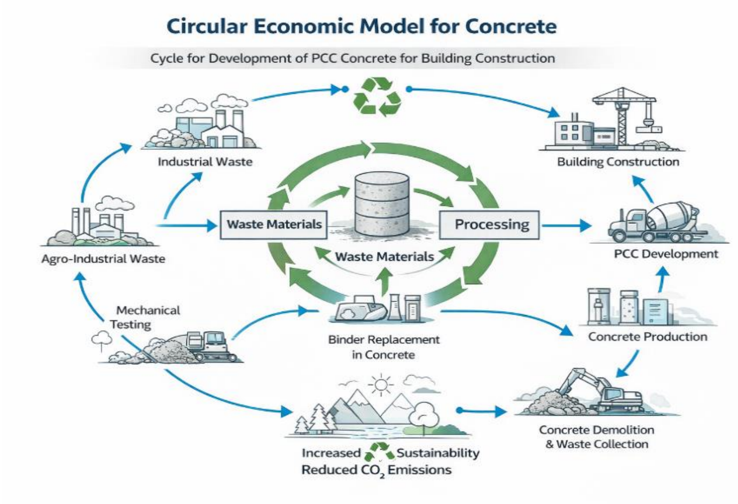

Figure 7. Circular economic model for waste utilization in PCC concrete.

5. Conclusions

The utilization of bio-based materials in this study has been done successfully. A series of research studies have been done in the past and ongoing to resolve this issue by using bio-based waste products to produce sustainable concrete. Additives like paper sludge as a replacement to binder were employed to investigate the mechanical and fresh characteristics of normal weight concrete. In this research study, fresh properties result of paper sludge was fine as compared to control sample because of their high degree of absorption. At each %replacement the behavior of concrete is analyzed. The compressive strength of concrete at 3% alternative of paper sludge is suitable for substitution, the compressive strength is almost similar for paper sludge with reference to cement binder. From the above conclusion, practically these waste materials can be used as binder or filler in large construction projects, especially for the construction of housing colonies. These types of structures are not heavily loaded like multistory buildings. The consumption of cement and sand can also be reduced by using such a waste material available in bulk.

6. Future Recommendations

Thus, in the future, it may be possible that experts can test paper sludge based composite materials against tensile and flexural strength. These bio-waste materials are cheaply available worldwide and the cost of construction could be reduced by utilizing these materials. This process will help to eliminate the environmental hazards and tends to decrease the cost production of traditional materials such as fine aggregates and cement where the sources are rare and expensive. In addition, this research resolves a land disposal problem of these waste materials by incorporating eco-friendly concrete and reduce the environmental hazard.

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