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Orginal Article

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Experimental analysis of concrete with partial cement replacement using incinerated hospital waste ash

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Abstract: The annual production of medical waste from healthcare facilities in Pakistan is around 250,000 tons. An effective waste management system is essential for disposing of hazardous medical waste, and incineration is considered the most effective and accessible technology. Disposal of medical waste ash in landfills without proper treatment could lead to groundwater contamination due to leachate. This research paper aims to evaluate the feasibility of using hospital waste ash obtained from the National Cleaner Production Center (NCPC) in Rawalpindi as a partial replacement for cement. The primary variable in this study was the amount of hospital waste ash (0%, 3%, 7%, and 10% by weight of cement), while the amount of cementitious material, water-to-cement ratio, and fine and coarse aggregate content were kept constant. A total of 36 cubes were cast, with nine cubes for each replacement level for curing periods of 7, 14, and 28 days. The slump value and density of fresh concrete decreased with the increase in the proportion of hospital waste ash in the mix. The compressive strength of mixes with 3% hospital waste ash was higher than that of the control mix. The best results (20.13 MPa) were obtained from the 3% mix after 28 days of curing, while the result obtained with the 7% mix was nearly equal to that of the control mix.

Keywords: biomedical waste ash, incineration, leachate, compressive strength, pozzolanic

1. Introduction

In Pakistan, population growth and ongoing processes are leading to the rapid depletion of natural resources, posing serious challenges to the country's sustainability and ecological development. As a result of the population increase, severe environmental degradation has occurred. The environment and natural resources are being contaminated, affecting people, animals, and plants [1]. Increased awareness of healthcare has created a demand for a wide range of medical facilities. It is undeniable that society is constantly striving to improve its health standards. The only way to enhance these standards is by establishing various public or private healthcare services. Hospitals are health institutions that provide patient care services by ensuring a clean and healthy environment for their staff and the community. However, the outcomes of healthcare institutions are not always entirely positive.

Due to advancements in healthcare technology, the amount of hospital waste generated is increasing, mainly because of the rise in the use of disposable products. These healthcare activities lead to the generation of various types of biomedical waste. Healthcare service centres may produce relatively large quantities of medical waste with a wide variety of characteristics and compositions. Due to its infectious nature, hospital waste is one of the leading causes of pollution. Although hospitals aim to improve patients' health, their waste disposal methods can raise concerns. Biomedical waste can be categorized into three main types based on the potential for causing injury or infection during handling and disposal: sharps (e.g., scalpel blades or needles), pathological wastes (e.g., biological cultures, blood samples, and anatomical body parts), and infectious wastes (e.g., surgical items contaminated with body fluids and discharges like IV lines, catheters, and dressings). Additionally, wastes such as polyvinyl chloride (PVC) plastics, devices containing mercury, and radioactive waste are some examples of waste that can be generated in healthcare settings [2]. If hospital waste is handled and disposed of alongside domestic waste, there is a high risk that scavengers could be exposed to blood-borne pathogens through needle-stick injuries. A further issue is the improper handling of hospital waste, which can contribute to the spread of blood-borne pathogens. Moreover, biomedical waste has the potential to negatively impact both the environment and its plant and animal inhabitants. Inadequately managed healthcare waste can serve as a reservoir of infectious microorganisms, which can be transmitted through direct contact with contaminated needles and syringes, through the air, or via various vectors. This can cause environmental pollution, unpleasant odours, and the proliferation of insects, worms, and rodents, potentially leading to the transmission of diseases such as cholera, typhoid fever, hepatitis, and AIDS [3].

Failure to adhere to biomedical waste management standards not only lowers the quality of health and life in society but also increases the burden on healthcare services. One of the primary requirements for effective management is the availability of reliable data and analysis of biomedical waste. Unfortunately, adequate investigations and statistical analyses of hospital waste in Pakistan are limited. The handling of healthcare waste is an essential component of infection control and hygiene programs in healthcare settings. Consequently, the practice of using alternative materials to cement in the construction sector has become more widespread [3].

Hospital waste, or medical waste, refers to any kind of solid, liquid, or fluid waste, including equipment or any intermediate product generated during the treatment, diagnosis, or protection of humans and animals, in research analysis, or during the production or testing of biological products. Ash from hospital waste is a specific category of this waste. Every human activity results in waste, and we are all aware that this kind of waste can be hazardous and requires proper disposal. Although there is currently significant variation in how hospitals manage medical waste, this issue is becoming an increasingly important environmental concern, especially in developing countries [4]. The compressive strength and durability of cured concrete with added biomedical waste ash have been evaluated, and results suggest that using this waste in concrete could be an effective way to enhance the material's value [5]. New cement-ash composite technologies have reportedly been assessed for potential future applications in the building sector, including cement matrices containing medical facility ash for structural uses [6].

Hospital waste is any kind of waste, either solid or liquid, that includes its containers or any product generated during the diagnosis, treatment, or protection of animals and humans in medical analysis. Most biomedical waste encompasses all types of waste that are discarded and not intended for further use in hospitals [7]. There are several substitutes for biomedical waste available, which are presently used interchangeably in various parts of the world and in numerous scientific papers. These commonly available substitutes include hospital waste, biomedical waste, and clinical waste [8]. The World Health Organization uses the term "healthcare waste" in its official publications and reports. Medical waste is any liquid or solid waste capable of causing infectious diseases, produced as a result of treatment, patient diagnosis, or related analysis during the protection of animals and humans [9].

Hospitals, private clinics, and nursing homes are places where patients receive care, but they are also significant sources of waste, which can be dangerous or hazardous. Historically, hospitals were established to treat those who were ill, but at that time, we were unaware of the negative consequences that could result from the waste produced by medical facilities. Similarly, we did not recognize that such waste poses serious health risks or contributes to pollution affecting human health and the environment.

A very small portion of municipal waste consists of medical waste. Greater attention needs to be paid to the proportion of garbage generated that is actually hazardous and infectious. The percentage of infectious medical waste within the total amount of medical waste is relatively small. The majority of waste that could potentially spread disease originates from clinical settings and hospital operations. The contribution from residential and industrial sources is minimal. According to the World Health Organization [10, 11], approximately 85 percent of medical waste is harmless in its natural state; about 10 percent is infectious waste; and approximately 5 percent of waste is harmless but falls into a risky category. In the United States, certain types of biomedical waste have been regulated since August 15, 1945, as they belong to the infectious category. In Pakistan, up to 20 percent of hospital waste is considered undoubtedly hazardous [12]. The amount of biomedical waste generated can vary, depending on hospital policies, practices, and the level of precautions taken. In Pakistan, this proportion may range from 10 percent to 30 percent of the total waste produced [13, 14]. The quantity of waste produced daily in different countries is shown in Table 1.

Table 1. Waste quantity generated per day in different countries

Country	Quantity (Kg/bed/day)
U.S.A	4.5
Spain	3.0
France	2.5
U.K.	2.5
Pakistan	1.5

The most important components of all plastic waste include items such as medical packaging, discarded plastics, sharps, tubes, blood bags, and IV bags. The most significant contributors to hospitals' total annual production of plastic waste are the operating rooms, laboratory cafeterias, and laboratory facilities [15]. As medical facilities begin to adopt the practices mentioned earlier, along with the involvement of medical personnel and the proportion of recyclable materials used in these facilities, this approach is starting to yield results for each medical facility [16].

According to one study, private hospitals in Gauteng produced between 0.06 kg/patient/day and 0.48 kg/patient/day of biomedical waste, while public hospitals produced between 0.002 kg/patient/day and 0.5 kg/patient/day [17]. In Pakistan, 25 percent of clinical solid and liquid waste is hazardous, while this figure is 26.5 percent in Nigeria and ranges from 2 to 10 percent in various sub-Saharan African countries [18]. According to studies [19] and [20], hospitals in the Kingdom of Thailand produce around 1 kg/bed/day [21]. It is important to note that data from individual doctors, dentists, medical clinics, veterinarians, long-term care services, independent blood care banks, and laboratories are not always reliable, and only a subset of healthcare establishments contributes to these statistics [22].

The novelty of this research lies in the systematic evaluation of Hospital Waste Ash (HWA) as a partial cement replacement in concrete. Although the use of medical waste ash in construction has been explored by some researchers, this study focuses on the specific properties and benefits of HWA obtained from the National Cleaner Production Center (NCPC) in Rawalpindi. By examining different replacement levels (0%, 3%, 7%, and 10%) and their effects on concrete properties, this research aims to provide a comprehensive understanding of the feasibility and advantages of incorporating HWA in concrete.

1.1. Objectives of the current study

To utilise hospital waste ash (HWA) in a cost-effective and environmentally friendly manner, efforts have been made to use it in concrete as a partial replacement for cement, with the following specific objectives:

- To investigate the impact of hospital waste ash on the strength properties of concrete as a partial replacement for cement.
- To introduce low-cost concrete using HWA.
- To address the hospital waste ash disposal problem.

2. Methodology and tests

2.1. Primary materials

The primary materials used in this research are hospital waste ash, ordinary Portland cement, water, fine aggregate, and coarse aggregate.

2.1.1. Hospital waste ash

The hospital waste ash was obtained from the NCPC. As shown in Fig. 1a, the collected ash contained both large and small particles, including shards of metal, broken glass bottles, and various needles, syringes, and other medical implements. This ash mixture was subjected to a sieve analysis using a No. 50 sieve, with the material retained after the process being discarded. Further grinding of the hospital waste ash was conducted using the Los Angeles

Abrasion Machine, which contained nine balls, each weighing approximately 450 grams (±5 grams). After sieving, the material collected was subjected to 4,000 revolutions to achieve a uniform fineness. The ash sample obtained after grinding is shown in Fig. 1b below.

Fig. 1. a) Hospital waste ash obtained from NCPC, b) HWA after grinding in Los Angeles Abrasion Machine

2.1.2. *Ordinary Portland cement*

The cement used was ordinary Portland cement (OPC) from Bestway Cement. It complies with the standards set by ASTM C150-04 Type I. The OPC used in this research is shown in Fig. 2a. The chemical properties of the cement and ash were determined according to ASTM standards (Table 2). Based on the chemical properties, HWA has the highest levels of CaO (approximately 31.2%) and the lowest levels of K2O (approximately 0.53%).

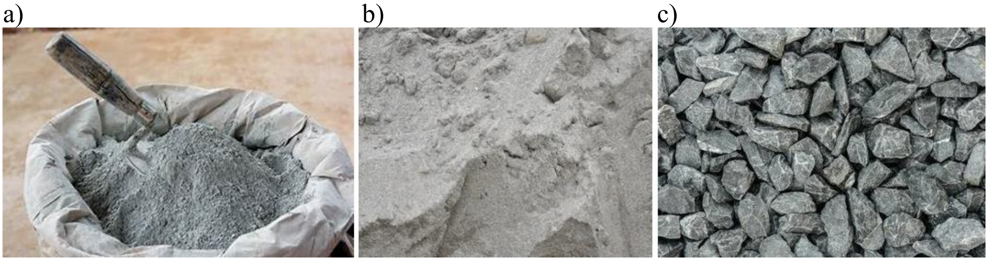

Fig. 2. a) Ordinary Portland cement, b) Lawrencepur sand, c) coarse aggregate

Table 2. Chemical properties of cement and ash

Chemical Components	Cement (%)	Ash (%)
Aluminum Oxide (Al_2O_3)	3.80	9.37
Ferric Oxide (Fe_2O_3)	3.7	5.2
Silicon Dioxide (SiO_2)	15.43	17.43
Calcium Oxide (CaO)	54.25	31.2
Sodium Oxide (Na_2O)	2.69	1.70
Potassium Oxide (K_2O)	1.09	0.53
Magnesium Oxide (Mg O)	2.1	2.0
Titanium Oxide (TiO_2)	0.6	3.2

2.1.3. Fine aggregate

The sieve analysis of the fine aggregate was conducted according to ASTM C136-01. Figure 2b shows a sample of fine aggregate from Lawrencepur sand. The fineness modulus of the fine aggregate is 2.40, which is commonly used in laboratories [23].

2.1.4. Coarse aggregate

Crushed stones from Margala with a nominal size of 20 mm were used as coarse aggregate. The sieve analysis was conducted according to ASTM C136-01. Figure 2c shows the coarse aggregate used in this research work.

2.2. Experimental matrix

Throughout this study, five unique mixtures were prepared. One control mix (CM) was made without adding any HWA, while the other four mixes contained varying amounts of HWA as a substitute for cement. The cement was replaced with HWA at levels of 0%, 3%, 7%, and 10% in different combinations. The mixtures were designed to achieve a 28-day compressive strength of 20 MPa. Table 3 shows the quantities of the different materials used in this research work.

Table 3. Experimental matrix

Mixes	Ratio	W/C ratio	Water (Lt)	HWA (kg)	OPC (kg)	Fine agg (kg)	Coarse agg (kg)
0%	1:2:4	0.55	6.36	0	11.57	23.11	46.28
3%	1:2:4	0.55	6.36	0.347	11.22	23.11	46.28
7%	1:2:4	0.55	6.36	0.80	10.77	23.11	46.28
10%	1:2:4	0.55	6.36	1.157	10.41	23.11	46.28

2.2.1. Casting details

The key variable in this analysis was the amount of hospital waste ash (3%, 7%, and 10% by weight of cement), while the quantity of cementitious material, water-to-cementitious material ratio, and coarse and fine aggregate content were kept constant. Four mixes were prepared in total. A total of thirty-six cubes were cast, with nine cubes for each mix.

3. Results and discussion

3.1. Gradation curve of fine aggregate

A curve, or S-curve, is used to illustrate the grading of aggregates. It is a logarithmic graph, with the sieve opening size on the horizontal axis and the cumulative percentage of particles passing on the vertical axis. The gradation curve of the fine aggregate indicates that the results obtained from our sieve analysis fall within the ASTM C33 specifications for fine aggregate. Figure 3 shows the gradation curve of the fine aggregate.

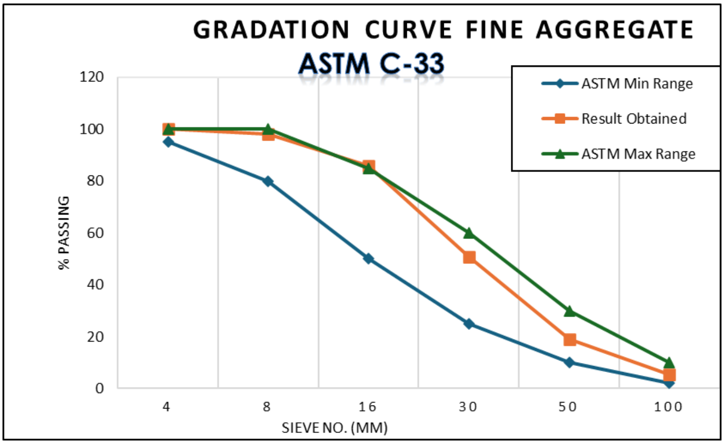

Fig. 3. Gradation curve of fine aggregate

3.2. Gradation curve of coarse aggregate

Aggregate grading is typically represented using a curve, or S-curve. The cumulative percentage of the specimen passing through the sieves is shown on the vertical axis, while the sieve openings are displayed on the horizontal axis, forming what is known as the "grading curve." The grading curve for a given sample indicates whether its grading meets the standards, or if it is too coarse, too fine, or lacking in a particular size range. The gradation curve of the coarse aggregate shows that the aggregates used in this research fall within the ranges specified by ASTM C33. Figure 4 illustrates the gradation curve of the coarse aggregate.

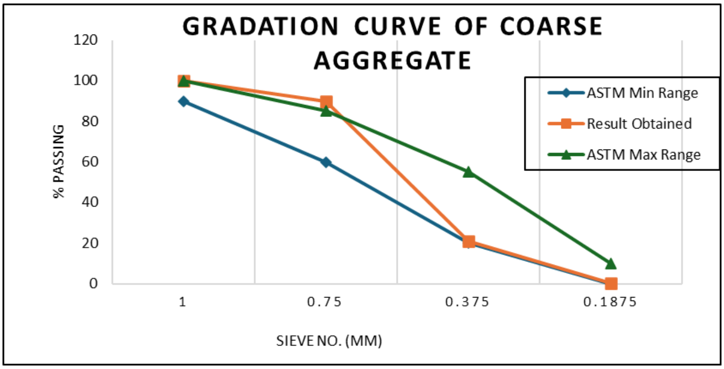

Fig. 4. Gradation curve of course aggregate

3.3. Summary of tests results of cement

Tests were conducted to check the fineness, consistency, specific gravity, and soundness in accordance with ASTM standards (Table 4). It was observed that the fineness values were below the maximum limit of 10%, which is an acceptable value for the modified cement when ash is used as a partial replacement. The consistency results were found to be close to the maximum value of the ASTM range, but this is not a significant concern; the modified cement remains better than the normal one. The specific gravity results were well within the acceptable range, indicating positive outcomes for this research.

Table 4. Summary of test results of fresh and modified cement

S.NO.	Characteristics	Results of fresh cement	Results of modified cement	ASTM range
1	Fineness % (C184-94)	2.8	3.0	0 – 10
2	Normal consistency % (ASTM C1870)	27.5	32	22 – 35
3	Specific gravity (g/cc) (ASTM D-792)	3	2.59	3.1 – 3.16
4	Soundness (cm) (ASTM C-151)	3	2.59	

3.4. Test conducted in fresh state

What does "fresh concrete" mean? It refers to the period between mixing the concrete and the start of curing. Concrete is produced through processes including mixing, transporting, placing, compacting, layering (finishing), and curing. Fresh concrete is also known as green concrete, plastic concrete, or workable concrete. Variables such as workability, consistency, strength, unit weight, density, air content, and temperature are tested in fresh concrete. Consistent testing helps identify slight changes in the concrete that may affect its durability. The following tests are conducted in the fresh state: the slump test and the density test.

3.4.1. Slump test

The slump test is a method used to determine the quality of fresh concrete, following ASTM C143 or AASHTO T119 standards. This experimental technique evaluates the workability of freshly mixed concrete and assesses the consistency between different batches. The simplicity of the procedure and the user-friendliness of the equipment contribute to the test's widespread adoption. A slump test was conducted for each mix. The slump value decreased as the hospital waste ash (HWA) content in the mix increased. As the proportions of HWA increased, the slump and workability of HWA-concrete decreased. This can be attributed to the void-filling action of the waste HWA, as it is finer than the fine aggregate, providing a higher level of cohesion to the mix [24]. The bar graph showing the slump values for different mixes is presented in Fig. 5.

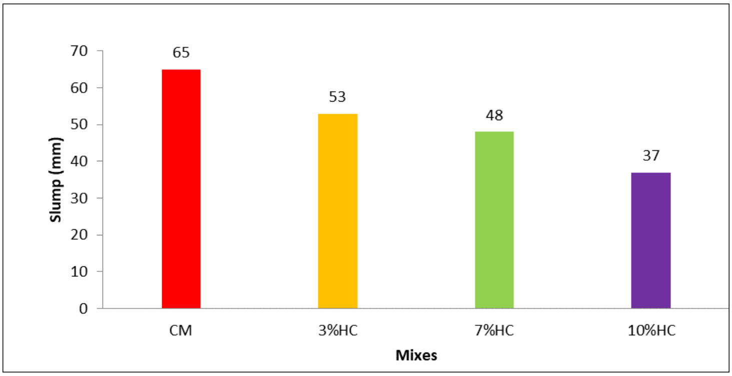

Fig. 5. Slump value of different mixes

3.4.2. Fresh concrete density

This test method covers the determination of the density of freshly mixed concrete according to ASTM C138/C138M-17a. The findings of the fresh concrete density for various blends are shown in Figure 6. The control mix (CM) had the highest fresh concrete density (2222.5 kg/m³) among the mixtures. The density decreased as HWA was used as a partial replacement for cement; furthermore, the higher the HWA concentration, the lower the density. This is typically since density is directly proportional to specific gravity. Since the specific gravity of cement is higher than that of HWA, the CM mix has the highest density. The results of the fresh concrete density tests for each mix are presented in Fig. 6. The setting time increased, while the density and water absorption of the mixes decreased, with an increase in the percentage of HWA in the mix [24].

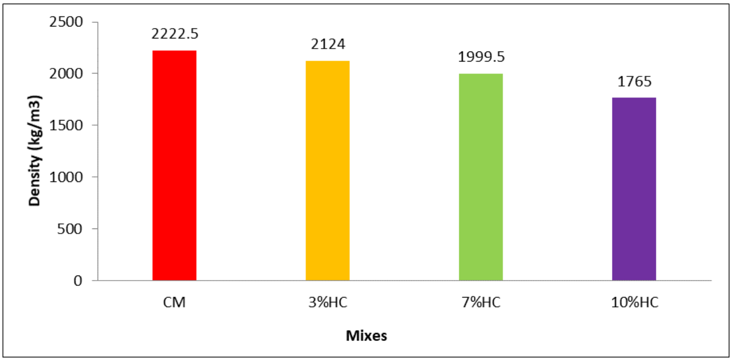

Fig. 6. Density of different mixes

3.5. Tests conducted in hardened state

The tests conducted in the hardened state are the water absorption and compressive strength tests.

3.5.1. Water absorption

The results of the water absorption test are graphically presented in Fig. 7. According to ASTM C1585, the test results indicated that water absorption increased with the rise in the amount of HWA used as a partial replacement for cement. This increase is attributed to the water-absorbing properties of HWA. The higher the HWA content, the greater the water absorption. It was also observed that the density of the concrete decreased slightly with an increase in the replacement level of biomedical waste ash (BMW) [25]. Biomedical waste ash can be effectively used in concrete, with up to a 10% replacement.

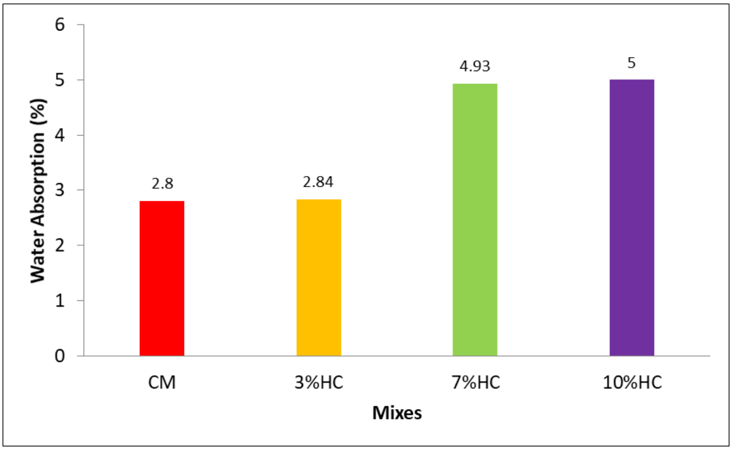

Fig. 7. Water absorption of different mixes

3.5.2. *Compressive strength test*

The maximum load at which the specimen breaks is considered the compressive load (ASTM C39). The load is applied to the specimen axially. The cubes should be placed correctly on the machine plate (align with the circular marks on the machine). Carefully align the sample with the spherically seated plate. Gradually apply the load at a rate of 140 kg/cm² per minute until the cube collapses. Figure 8 provides a graphical representation of the compressive strength results for various mixtures at 7, 14, and 28 days, respectively. For all types of mixes, the compressive strength increased with the curing period, from 3 to 28 days, but decreased with the addition of HWA as a partial replacement [26]. The use of HWA up to 10% showed the best results. At 3 days of testing, the mixes containing HWA exhibited higher strength than the control mix (CM), likely due to the presence of calcite in the HWA.

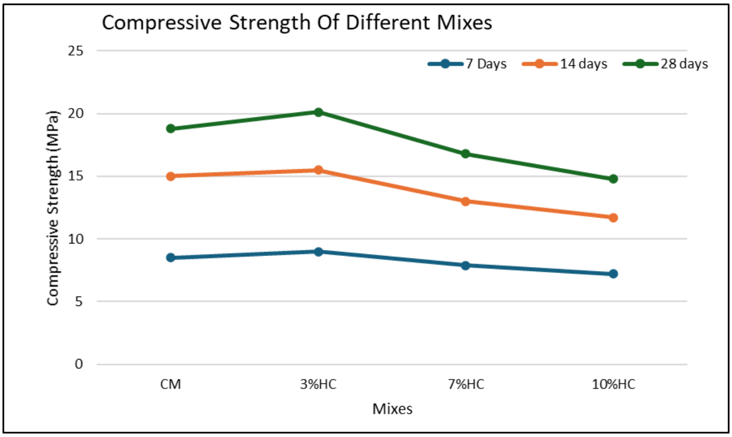

Fig. 8. Compressive strength of different mixes

The compressive strength test data shows that:

- For every mix, the compressive strength increased with the curing period, from 3 to 28 days.

- At 3% HWA, the mix showed higher strength than the control mix (CM). This could be due to the presence of calcite in the HWA.

The 7- and 28-day compressive strength of the CM was higher than that of the mixes containing HWA, except for the 3% mix. The increase in compressive strength at 3% is also attributed to the microfiller effect, which requires further validation through scientific investigation, such as analysing SEM images of the CM and 3% mix at different ages. When comparing the 7% mix with the 10% mix, the 7% mix showed higher strength at each testing stage, indicating that the quantity of cementitious material plays a significant role. This is because, in the 10% mix, the cement replacement is greater compared to the 7% mix, making the latter richer in cement content. Therefore, when the hydration of Portland cement begins, the primary silicates, specifically tri-calcium silicate, di-calcium silicate, and tri-calcium aluminate, which are crystalline in nature, decompose rapidly in water to release the necessary silicate and aluminate ions for forming cementitious hydrates. Hence, a mix with a higher cement content is likely to achieve higher compressive strength.

4. Cost comparison

The cost comparison was made between the control mix (CM) and the 7% mix, which had nearly similar compressive strengths. Based on the cost analysis, the 7% mix design was found to be approximately 5% cheaper than the CM. Table 5 presents the cost comparison between the CM and the 7% HWA mix.

Table 5. Cost comparison

Material	Rate per kg	Control Mix CM		Mix with 7% HWA	
		Quantity	Amount	Quantity	Amount
	(Rupees)	(kg)	(Rupees)	(kg)	(Rupees)
Cement	10.5	11.57	121.48	10.77	109
Sand	0.35	23.11	8.0	23.11	8.0
Hospital waste ash	Free of Cost	0	—	0.80	free
Coarse aggregate	1.467	46.28	67.89	46.28	67.89
Total			197.37		184.89

5. Conclusions

Based on the experimental results, the following conclusions can be drawn:

- The feasibility of using HWA as a partial replacement for cement has been established.
- HWA is identified as a suitable material for concrete production, meeting the physical and chemical property standards of American codes of practice.
- Incorporating HWA in concrete can lower production costs without compromising strength properties.
- Higher HWA content increases setting time, densifies the mix, and reduces water absorption.
- Using HWA in concrete helps address disposal issues, reducing environmental contamination and conserving natural resources.

- Workability and slump values decrease with increased HWA content, while water absorption increases and mix density decreases.
- A 3% HWA replacement demonstrates high strength, while a 7% replacement provides a more balanced and cost-effective alternative.
- Cement production contributes to 5% of global human-produced CO2 emissions; substituting cement with HWA can help reduce these emissions.

6. Recommendations

- Research should also be conducted on municipal solid waste (MSW) since it is generated in large quantities daily in Pakistan.
- Further studies should be undertaken to determine whether MSW can be used in concrete structures.
- Water absorption is an issue associated with HWA mixes, which needs to be addressed through further chemical testing.
- In future research, additional scientific investigation should be conducted to validate the outcomes.

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