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ECO FRIENDLY UTILIZATION OF WASTE PET BOTTLES AS PARTIAL REPLACEMENT OF SAND AND BAGASSE ASH AS PARTIAL REPLACEMENT OF CEMENT IN CONCRETE

By

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Abstract

This research aimed to investigate and introduce locally available materials, PET (Polyethylene Terephthalate) and Bagasse ash, as partial replacements for sand and cement, respectively, in concrete. The overall goal was the eco-friendly utilization of waste PET bottles as a partial replacement of sand and bagasse ash as a partial replacement of cement in concrete. Specific objectives included analyzing the physical and chemical properties of these materials, investigating their effects on concrete characteristics (workability, unit weight, quality, and strength), and determining the optimum proportion for substitution. The ACI mix design was used for the experimental analysis. The methodology involved casting cubical specimens (150 × 150 × 150 mm) from concrete mixtures where sand was replaced by PET and cement was replaced by bagasse ash, separately and simultaneously, at 0%, 5%, 10%, and 15% substitution levels. Testing was conducted to determine the fresh and hardened behavior of the concrete, including workability (slump), unit weight, compressive strength, and Ultrasonic Pulse Velocity (UPV). The experimental results showed a reduction in unit weight, pulse velocity, and compressive strength. However, an increase in slump values (workability) was observed in the modified concrete mixes. Crucially, despite the reduction in strength, the strength achieved at the 15% replacement level (17.943 MPa or 2601.735 psi) still satisfied the minimum specified compressive strength (2500 psi) for structural concrete as per ACI 318 Standard Section 5.1.1. This approach significantly contributes to sustainability by demonstrating that 99.610 kg/m³ of sand and 73.756 kg/m³ of cement can be saved at the 15% replacement level. Future research is suggested to investigate these materials in self-compacting and high-performance concrete and to use treated bagasse ash to enhance its pozzolanic properties.

Key Words: *Eco friendly Utilization, Waste pet bottles, Bagasse ash , Sand, Concrete, Hardened concrete, Ultrasonic pulse velocity (upv)*

Introduction

Concrete is universally acknowledged as the most widely utilized material in construction, prized for its inherent strength, durability, and resistance to diverse environmental stresses [1]. Its fundamental composition relies on a mixture of cement, water, and aggregates, with the latter, such as sand, gravel, or crushed stone, making up approximately two-thirds of the total volume [2]. The reliance of modern construction practices on these conventional components places considerable strain on finite natural resources. After water, concrete is the second most used substance globally [3]. It is estimated that approximately 25 billion tons of concrete are manufactured globally each year, requiring vast quantities of natural aggregates and consuming about 2 billion tons of Portland cement [4]. This prodigious consumption of raw materials, particularly in cement production, is a major contributor to environmental degradation, including the potential release of greenhouse gases that lead to global warming [5].

The environmental consequences associated with cement manufacturing are increasingly prominent, given that cement industries are responsible for around 2.5% of total worldwide waste emissions from industrial sources [6]. Specifically, the production of just one ton of cement results in the emission of approximately 0.8 tons of CO_2, accounting for an estimated 5–

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8% of worldwide CO_2 emission [7]. Concurrently, the dual forces of rapid urbanization and industrialization have resulted in an alarming escalation of waste generation, presenting significant environmental challenges [8]. Among these waste streams, discarded Polyethylene Terephthalate (PET) bottles and bagasse ash (a byproduct of sugarcane processing) represent both a disposal problem and a potential resource. While PET bottles, a lightweight and strong plastic used for packaging, are technically recyclable, global data indicates that only 9% of plastic waste is actually recycled, with 50% ending up in landfills and 22% evading formal waste management systems [9]. Bagasse ash, the fibrous residue obtained after sugarcane juice extraction, is generated when this material is combusted for energy generation in sugarcane mills [10].

To address both the depletion of natural resources and the environmental pressures caused by overflowing landfills, the integration of recycled and waste materials as substitutes for conventional construction inputs is essential [11]. This research is specifically focused on the environmentally conscious utilization of waste PET bottles as a partial replacement for sand and bagasse ash as a partial replacement for cement in concrete production. By successfully incorporating these waste materials into construction, this study seeks not only to reduce the pressure on landfills but also to develop more sustainable and resilient building practices, thereby guiding the construction industry towards a greener future [12]. The fundamental aim of the investigation is to evaluate and introduce locally available PET and Bagasse ash materials as effective substitutes for sand and cement, respectively [13].

Objective:

The study outlined specific objectives, including the analysis of the physical and chemical properties of the waste PET and Bagasse ash, particularly examining the pozzolanic characteristics of the ash [14]. The experimental methodology involved determining the behavior of concrete when these substitutions were implemented, specifically assessing workability, unit weight, quality, and strength [15]. Utilizing the ACI mix design methodology, cubical specimens (150 x 150 x 150 mm) were cast. The experimental programme involved three primary substitution approaches: first, replacing sand with PET at 0%, 5%, 10%, and 15% levels; second, replacing cement with bagasse ash at the same substitution levels; and finally, implementing the simultaneous replacement of both sand (by PET) and cement (by bagasse ash) at these proportional levels [16]. Subsequent testing evaluated the fresh concrete properties (using the slump cone test for workability and determination of unit weight), and the hardened concrete mechanical properties, including compressive strength and ultrasonic pulse velocity (UPV) [17]. Ultimately, the research sought to confirm the viability of using these waste materials as conventional substitutes, establish the optimum replacement proportion, and provide practical solutions to environmental issues such as CO2 emissions and landfilling, which could also lead to reduced material costs [18]. Preliminary results indicated that incorporating these materials led to a reduction in unit weight, pulse velocity, and compressive strength, although an increase in slump values was observed [19].

Literature Review

The literature review for this research focuses on the significant progress reported in the utilization of waste Polyethylene Terephthalate (PET) and sugarcane bagasse ash (SCBA) as sustainable substitutes for conventional concrete components. This summary examines prior investigations into the effects of replacing fine aggregates with PET waste and replacing cement with bagasse ash.

Numerous studies have investigated the feasibility and impact of using waste PET plastic as a partial replacement for fine aggregate (sand) [20]. Generally, the incorporation of PET particles has been linked to changes in the physical and mechanical characteristics of the resulting concrete [21].

Research by Almeshal et al., which tested substitution levels up to 50%, observed a reduction in unit weight and a detrimental effect on the concrete's mechanical properties at varying rates, concluding that specific ratios of plastic waste could be effectively applied in industrial usage for disposal [22]. Similarly, Dawood et al. found that density and ultrasonic pulse velocity (UPV) gradually decreased as PET ratios increased, while the absorption rate increased.

Regarding strength, results are varied, depending largely on the substitution percentage. Dawood et al. noted that specimens containing partial substitution ratios between 5% and 12.5% displayed increments in compressive strength (26.8%-43.64%), tensile strength (18.6%-26.9%), and flexural strength (18.1%-30.2%) compared with reference specimens [23]. However, strength parameters decreased when the PET content exceeded 15%. Similarly, Nadimalla et al. identified that compressive strength enhanced up to 5% to 10% substitution of fine aggregate, diminishing at 15% and 20% replacements [24]. They also found that flexural and split tensile strength improved up to 10% addition [25]. In contrast, Amibo et al. reported a slight increase in compressive strength only up to 3% replacement, with a reduction beyond that level. Bandodkar et al., testing M20 concrete with replacements up to 10%, reported a strength reduction of up to 13.5% [26].

The physical characteristics of PET fragments also influence the fresh properties of concrete. Nadimalla et al. noted that the non-uniform, angular, and sharp edges of the PET bottle aggregates reduced the slump value of concrete mixes [27]. Furthermore, Frigione's study, replacing 5% of fine aggregate with waste PET, found that the resulting concretes exhibited workability characteristics similar to the reference mix but slightly lower compressive and splitting tensile strength, alongside moderately higher ductility [28].

The use of sugarcane bagasse ash (SCBA), an agro-waste product, is highly relevant due to its pozzolanic properties [29]. Pozzolana are materials containing reactive silica and/or alumina that, when finely divided, react with calcium hydroxide produced during cement hydration, forming stable

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calcium silicates that exhibit cementitious properties. The reactivity of natural pozzolanic materials can potentially be enhanced by heating them in temperatures ranging from 550 to 1100 ºC [30].

Studies have consistently shown the potential of SCBA as a partial replacement for Ordinary Portland Cement (OPC). Khalil et al. concluded that SCBA exhibits high silica content, the chemical composition of which is sensitive to the incineration method, time, temperature, and grinding mechanism [31]. They noted that concrete containing SCBA generally requires less water to achieve the same workability compared to conventional concrete [32].

Numerous studies pinpoint substitution levels that yield satisfactory or enhanced performance:

Mangi et al. observed that compressive strength increased with SCBA incorporation [33]. They determined that 5% replacement in M20 concrete increased the average compressive strength by 12% compared to Normal Strength Concrete (NSC), suggesting this as the proportion for maximum strength attainment. Furthermore, they found that SCBA produced compatible slump values, improving workability [34].

Other researchers similarly found optimal performance at low substitution levels. Srivastava et al. and Reddy et al. suggested an advantageous replacement limit of up to 10% without substantial strength loss [35]. Khalil et al. indicated that replacements of 10% by weight allow for excellent mechanical performance and durability [36].

Some studies explored higher percentages, with promising results: Kiran and Kishore found that SCBA could be used up to 15% without major loss in strength [37]. Chusilp et al. found that concrete containing 20% ground bagasse ash had the highest compressive strength, reaching 113% of the control concrete [38]. They also noted that water permeability decreased and heat evolution was lower with increasing BA replacement [39].

Dineshkumar and Balamurugan concluded that the 20% replacement mix showed the most positive results in high-strength concrete, improving mechanical properties and durability, including reduced water absorption and corrosion resistance [40].

Abdulkadir et al. reported that 10% and 20% replacement of SCBA satisfied the ASTM-595 PAI specification, with 10% SCBA replacement recommended for reinforced concrete [41].

Research has also explored how SCBA influences durability and material integrity. Quedou et al. reported that at 120 days of curing, compressive strength increased slightly for 5% and 10% replacement levels, concluding that 10% replacement is suitable [42]. Khalil et al. noted that using ultrafine bagasse ash improved resistance to chloride penetration, suggesting that up to 20% substitution decreased the number of coulombs [43].

Bahurudeen et al. specifically assessed the pozzolanic activity, concluding that raw SCBA has low activity due to fibrous carbon content, but its removal significantly improves pozzolanic activity (from 69% to 79%) [44]. Processed SCBA blended cements showed increased resistance against chloride, air, and water permeability compared to control concrete [45].

The limited literature available on the combined use of these materials suggests potential benefits, particularly if the SCBA is used to treat the PET waste [46]. Salhotra et al. coated PET fibers (PET-Fs) with SCBA. While the incorporation of PET-Fs generally reduced concrete properties (compressive, split tensile, flexural strength, workability, and density), concrete containing the coated PET-Fs exhibited better properties than those with uncoated fibers, suggesting that the coating process can enhance the applicability of PET-Fs as a construction material [47]. Anusha et al. also successfully demonstrated the effective use of PET waste as a filler material alongside partial SCBA replacement for cement in paver block manufacturing [48].

Materials and Methods

Ordinary Portland Cement (OPC) (lucky cement brand) was used, along with aggregates characterized in Tables 1 and 2, For mortar, sand passed a No. 16 sieve; for concrete, the fine aggregate passed a No. 4 sieve, and the coarse aggregate was crushed stone with a maximum size of 19 mm.

Table 1. Properties of fine aggregate

Property	Code	Result
Specific Gravity	ASTM C 128	2.48
Fineness Modulus	ASTM C33	2.2
Absorption (%age)	ASTM C 128	---

Table 2. Properties of coarse aggregate

Property	Code	Result
Specific Gravity	ASTM C 127	2.89
Fineness Modulus	ASTM C136	3.81
Absorption (%age)	ASTM C 127	0.33

Waste PET (Polyethylene Terephthalate), readily available from recycling units, was used as a partial replacement for sand [49]. The PET utilized in this research, sourced from Shah Gee Pet Bottle Recycling Unit Faisalabad, passed a No. 4 sieve. Its properties specific gravity, fineness modulus, and absorption are presented in Table 3.

Table 3. Properties of Pet (Polyethylene Terephthalate)

Property	Code	Result
Specific Gravity	ASTM C 128	1.66
Fineness modulus	ASTM C33	3.7
Absorption (%age)	ASTM C 128	0

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The bagasse ash used in this research was passed from sieve no.100 and obtained from Ansari Sugar mills Matli. The bagasse ash is utilized as pozzolanic material in concrete and mortar as partial cement replacement material.

Mix Proportion of mortar for strength activity index

To determine the Strength Activity Index (SAI) of the bagasse ash, four mortar mixtures were prepared with a 20% cement substitution of bagasse ash by weight. The mixtures adhered to ASTM C 311 guidelines, using a sand-to-cementitious material ratio (S/C) of 2.75 and a water to-binder ratio (w/b) of 0.49. Mixing, compaction, and molding followed ASTM C305 and ASTM C109. The specimens were demolded after 24 hours and cured in a wet environment for 7 days.

Table 4 Mix Proportion of mortar

Mix ID	Cement (%)	w/b	Sand/Binder
A	100	.49	2.75
B	80	.49	2.75

Three 50×50×50 mm mortar cubes were cast for each mixture. Mixing took place on a non-porous platform, where dry materials were first mixed until homogenous, followed by the addition of water to create a uniform mortar. After filling the molds, cubes were demolded after 24 hours, placed in a curing tank, and tested at the age of 7 days.

Characterization of bagasse ash by X-Ray diffraction analysis

Chemical composition of bagasse ash

Chemical composition of bagasse ash was determined by energy dispersive spectrometry (EDS) using EDS machine.

Mix proportioning of concrete

Concrete mixtures were proportioned using the ACI mix design with a w/b ratio of 0.41 and a 3-4 inch slump range. A total of ten mixtures were prepared: one OPC control mix and nine modified mixtures at 5%, 10%, and 15% substitution levels. Substitutions included: 5%, 10%, and 15% replacement of sand with PET; 5%, 10%, and 15% replacement of cement with bagasse ash; and simultaneous 5%, 10%, and 15% replacement of both. Three cubes were cast per mixture. All concrete was mixed per ASTM C192 using a revolving pan mixer, maintaining constant aggregate gradation [50].

Table 5. Mix proportion of concrete

Mix id	Cement kg/m3	F.A kg/m3	C.A kg/m3	Pet kg/m3	B.A kg/m3	w/b	Water kg/m3
CM	491.707	664.071	992	--	--	0.41	201.5999
P5	491.707	630.867	992	33.203	--	0.41	201.5999
P10	491.707	597.662	992	66.407	--	0.41	201.5999
P15	491.707	564.460	992	99.610	--	0.41	201.5999
B5	467.121	664.071	992	--	24.585	0.41	191.5196
B10	442.536	664.071	992	--	49.170	0.41	181.4398
B15	417.950	664.071	992	--	73.756	0.41	171.3595
PB5	467.121	630.867	992	33.203	24.585	0.41	191.5196
PB10	442.536	597.662	992	66.407	49.170	0.41	181.4398
PB15	417.950	564.460	992	99.610	73.756	0.41	171.3595

Results and Discussions

The results of 7 days compressive strength of mortar prepared with substitution of cement with bagasse ash is presented in table 6 and figure 1.

Table 6. Compressive strength of mortar at 7 days

Mix ID	Compressive strength (MPa)
A (control mix)	9.88
B (modified)	7.16

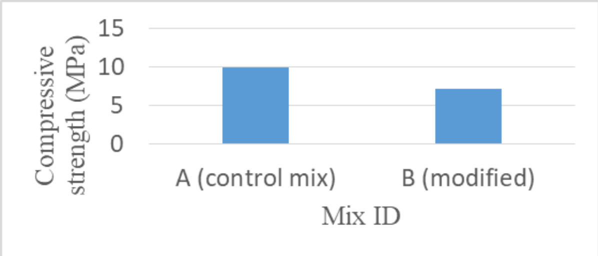

Figure 1. Compressive strength of mortar at 7 days

The achieved SAI (%) is less than required SAI (%) which should be ≥ 75% for the material to be used as pozzolanic material in concrete as per ASTM C618.

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Characterization of bagasse ash by X-Ray diffraction analysis

X-ray diffraction test was carried out on bagasse ash. XRD analysis of bagasse ash is presented in figure 2 and table 7.

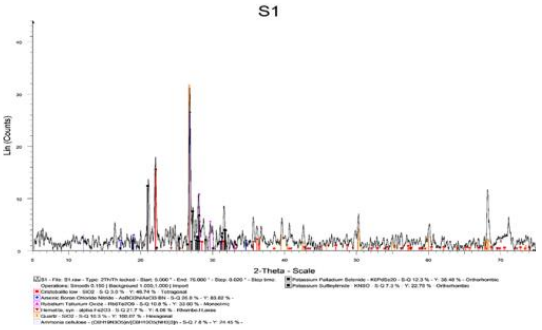

Figure 2 XRD pattern of bagasse ash

Table 7. Mineralogical compositions of bagasse ash

Mineral	Bagasse ash (%)
Quartz	10.3
Cristobalite	3.0
Arsenic Boron Chloride Nitride	26.8
Rubidium Tellurium Oxide	10.8
Ammonia Cellulose	7.8
Hematite	21.7

The X-Ray Diffraction (XRD) analysis revealed the mineralogical composition of the bagasse ash:

- **Quartz (SiO2):** Indicates quartz grains and does not significantly contribute to pozzolanic activity.
- **Cristobalite (SiO2):** Suggests high-temperature exposure and also doesn't contribute significantly to pozzolanic activity.
- **Contaminants:** Arsenic Boron Chloride Nitride and Rubidium Tellurium Oxide are present, potentially from contaminants.
- **Organic Matter:** Ammonia Cellulose indicates organic matter, which can reduce pozzolanic activity.
- **Hematite (Iron ore):** May have a small positive influence on the pozzolanic reaction.

The presence of impurities and inert materials negatively affects the ash's pozzolanic properties [51]. Additional processing, like calcination, may be required to reduce impurities and enhance its suitability as a supplementary cementitious material.

Chemical composition of bagasse ash

The chemical composition of bagasse ash is determined by Energy dispersive spectrometry (EDS). The chemical composition of bagasse ash is presented in table 8 and presented in figure 3.

Table 8. Element percentage by weight of bagasse ash

Element	Series	C norm{wt.%}	C Error{%}
Carbon	K-series	10.72	10.2
Oxygen	=	49.42	5.5
Sodium	=	1.32	0.1
Magnesium	=	1.22	0.1
Silicon	=	20.96	0.8
Potassium	=	8.19	0.3
Calcium	=	3.10	0.1
Iron	=	1.48	0.1
Phosphorus	=	0.67	0.1
Sulfur	=	0.85	0.1
Chlorine	=	0.93	0.1
Aluminium	=	1.13	0.1
Total	=	100.00	100.00

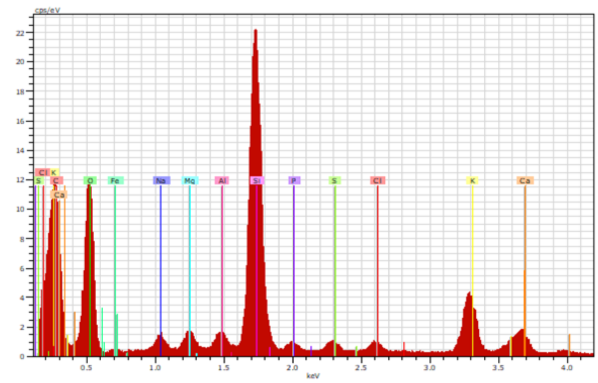

Figure 3. EDS of Bagasse ash

According to ASTM C 618, the minimum requirement for a pozzolanic material is; $SiO_2 + Al_2O_3 + Fe_2O_3 \geq 70\%$ but in this case $SiO_2 + Al_2O_3 + Fe_2O_3 = 49.0911\%$ which is less than minimum requirement which means bagasse ash used in this research possess less pozzolanic properties.

Fresh properties of concrete

Workability

Workability of control and modified concrete was determined by slump cone test as per ASTM C143 and the results are presented in Figure 4.

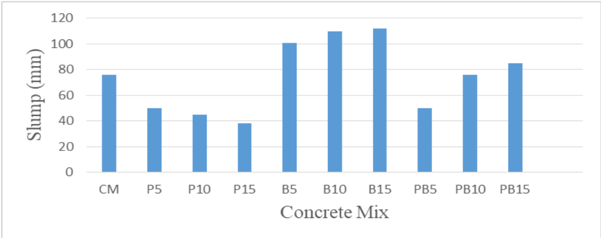

Figure 4. Workability of control and modified concrete

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Workability (slump) results, shown in Figure 4, indicated a decrease when sand was replaced with PET due to the non-uniform and irregular shape of PET particles. Conversely, workability increased when cement was replaced with bagasse ash (BA) [52]. This increase is attributed to the finer BA particles acting as fillers, which lubricate the mixture, reduce friction, and lower water demand. The simultaneous replacement of both sand with PET and cement with BA also resulted in an overall increase in workability, primarily due to the effect of the BA and the glassy surface of the PET.

Unit weight of concrete

The unit weight of control and modified concrete was determined as per ASTM C138 and the results are tabulated in table 9.

Table 9. Unit weight of control and modified concrete

Concrete Mix	Unit weight (kg/m3)	Decrease (%)
CM	2430.46	--
P5	2325.8	4.306
P10	2258.0	7.095
P15	2186.44	10.04
B5	2423.7	0.29
B10	2355.931	3.066
B15	2288.131	5.856
PB5	2306.95	5.081
PB10	2259.882	7.018
PB15	2193.97	9.730

The unit weight of the concrete consistently decreased with all substitution methods, as shown in Table 9. Replacing sand with PET reduced the unit weight due to the low density of the plastic. Similarly, replacing cement with bagasse ash (BA) caused a reduction because BA has a lower density than cement. Consequently, the simultaneous replacement of both sand with PET and cement with BA also resulted in a decreased unit weight [53-54].

Mechanical properties of concrete

To check the integrity of material and quality of concrete with substitution of sand with pet and cement with bagasse ash. UPV test of concrete has been carried out. The UPV of control and modified concrete is investigated at 28 days and tabulated in table 10.

Table 10. Ultrasonic pulse velocity of control and modified concrete

Concrete Mix	UPV (km/sec)	Decrease (%)
CM	5.786	
P5	5.453	5.755
P10	5.244	9.367
P15	5.12	11.510
B5	5.601	3.197
B10	5.301	8.382
B15	4.412	23.746
PB5	5.028	13.100
PB10	4.667	19.339
PB15	4.516	21.949

The ultrasonic pulse velocity of concrete is decreased by replacing sand with pet as mentioned in table 10. Because concrete porosity was affected negatively by adding pet, these cavities formed by the pet particles attenuate the ultrasonic wave due to the acoustic impedance. Concrete, Pet and holes are materials that partially reflect and transmit the incident wave, thereby decreasing its velocity. Also when cement is replaced with bagasse ash reduction in UPV is observed which is due to slow reaction at early stages, low density, porosity and weak intergranular bonding [55]. In last when sand is replaced with pet and cement with bagasse ash reduction in UPV is observed as mentioned in the table 10.

Compressive strength of concrete

The compressive strength is performed as per ASTM C39 and the results of compressive strength of control and modified concrete at 28 days is presented in figure 5.

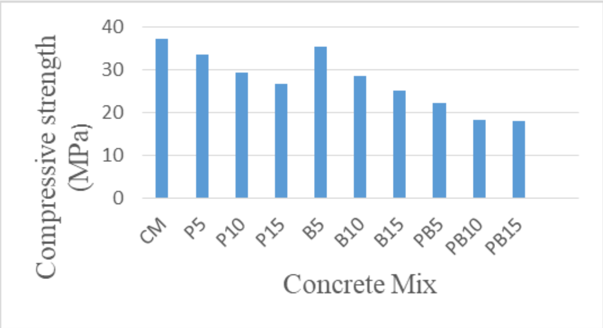

Figure 5. Compressive Strength of control mix and modified concrete

The compressive strength of concrete containing pet as partial replacement of sand reduced due to poor bonding, reduced stiffness, void spaces, and lower density. The results agrees with findings of other researchers. Also the compressive strength of concrete containing bagasse ash as partial replacement of cement decreased due to lower pozzolanic properties of bagasse ash as compared to cement the results are in accordance with findings of other researchers [56]. The compressive strength of concrete containing waste pet as partial replacement of sand and bagasse ash as partial replacement of cement also reduced as shown in figure 5.

Conclusion and Future Contribution:

The main theme of this research was the eco-friendly utilization of waste PET bottles as a partial replacement of sand and bagasse ash as a partial replacement of cement in concrete. The experimental program investigated the suitability of these locally available waste materials as substitutes for conventional construction materials. The

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findings demonstrated that replacing both sand with PET and cement with bagasse ash resulted in increased workability and decreased unit weight of the fresh concrete mixes when compared to the Control Mix (CM). While the investigated mechanical properties, specifically compressive strength and Ultrasonic Pulse Velocity (UPV), decreased with the substitution, the minimum specified compressive strength for structural concrete (2500 psi, as per ACI 318 Standard Section 5.1.1) was still achieved, with the 15% replacement mix reaching 17.943 MPa (2601.735 psi). This approach offers a significant contribution by saving natural resources, allowing for the saving of 99.610 kg/m³ of sand and 73.756 kg/m³ of cement at the 15% replacement level. For future contributions, the research suggests extending this work to investigate the use of PET and bagasse ash in self-compacting and high-performance concrete. Additionally, future studies should explore using treated bagasse ash to improve its pozzolanic properties when used as a cement replacement alongside PET as a sand replacement in concrete.

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