Feasibility of Using Baghouse Dust from Asphalt Plants as Partial Replacement of OPC in M20 Concrete

Sundar Adhikari[1*], Anu Adhikari[1], Om Prakash Giri[1], Rajendra Aryal[1], Bishwash Poudel[2]
[1] School of Engineering, Faculty of Science and Technology, Pokhara University, Pokhara, Nepal
[2]Madan Bhandari College of Engineering, Morang, Nepal
*adsundar@pu.edu.np

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Abstract

Concrete production heavily relies on ordinary Portland cement (OPC), which significantly contributes to global CO_2 emissions and raises construction costs. Reusing industrial byproducts becomes an important step toward sustainability. However, the potential of baghouse dust (BHD) from asphalt plants as a cement substitute remains largely unexplored in Nepal, creating the need to assess whether this plentiful waste material can partially replace cement without compromising concrete quality. This study examined the feasibility of using BHD from an asphalt plant in the Pokhara Valley as a partial replacement for OPC in M20 concrete, with BHD used at 0%, 5%, 10%, and 15% replacement levels, while maintaining a water-to-cement ratio of 0.40. The study evaluated the properties of fresh concrete, including slump and bulk density, as well as the hardened properties of compressive, split tensile, and flexural strengths at both 7 and 28 days. Water absorption tests were also performed at 28 days to assess permeability. Results indicated that the slump slightly decreased as the BHD content increased, while the bulk density dropped by about 2–2.5% at a 15% replacement, reflecting minor changes in workability and particle packing. Mechanical testing revealed that a 5% BHD replacement yielded the best performance, improving strength at both ages. In contrast, higher dosages (10–15%) reduced strength due to binder dilution and increased micro-voids. Water absorption marginally increased at 5–10% replacement due to finer particle packing and micro-pore refinement, indicating a denser microstructure, but increased at 15%, likely due to higher porosity. Overall, the findings suggest that BHD can be effectively reused as a low-level (5–10%) cement replacement to improve strength and durability in non-structural and moderately loaded concrete applications, provided the source quality and long-term behavior are properly evaluated.

Keywords: Compressive Strength, Baghouse Dust (BHD), Flexural Strength, Ordinary Portland Cement (OPC), Split Tensile Strength, Water Absorption, Density.

1. Introduction

Concrete is the most widely used man-made material and underpins modern infrastructure, yet its principal binder ordinary Portland cement (OPC) is energy-intensive and a major source of anthropogenic CO_2 emissions. Global estimates commonly attribute around 7–8% of CO_2 emissions to cement production which motivates strategies to lower embodied carbon in concrete through reduced cement content, improved production efficiency, or partial substitution of OPC with supplementary cementitious materials (SCMs) and mineral fillers. One underutilized waste stream with potential in this regard is baghouse dust (BHD) from asphalt mixing plants: ultrafine particulate matter collected by fabric filters during aggregate heating and asphalt mixing. BHD typically contains mineral fines derived from the aggregate, minor oxides (SiO2, CaO, Al2O3, Fe2O3), and often traces of residual bitumen or other organics; its properties vary with feedstock, plant operation and fuel. In many settings, including Nepal, BHD is stockpiled or landfilled, creating environmental and land-use concerns while representing a potentially valuable material for partial cement replacement if deployed safely and effectively.

Existing research on industrial fines and by-products demonstrates that very fine particles can produce a beneficial filler effect: by filling micro voids in the cement paste and interfacial transition zone, they can increase packing density, refine pore structure, and in some cases provide nucleation sites for hydration products that accelerate early strength gain (Mehta & Monteiro, 2006). Studies on materials analogous to BHD such as foundry sand, cement kiln dust and various mineral fillers show consistent patterns: low replacement levels (commonly ≤10%) often yield neutral to positive effects on strength and permeability, whereas higher dosages tend to dilute the hydraulic binder, increase porosity and reduce mechanical performance unless compensated by reactive SCMs or chemical activation (Mohanty et al., 2019; Miah et al., 2023). Specific investigations into asphalt plant powders and Asphalt Plant Waste Powder (APWP) are limited but encouraging; several reports indicate that 5–10% replacement can improve compressive and flexural properties in certain mixes (I et al., 2024; Razak et al., 2025), while others underline the variability of outcomes due to differences in BHD composition and organic residues.

Two practical concerns frequently highlighted in the literature must be addressed before recommending BHD reuse at scale. First, residual bitumen and solvent-extractable organics may be hydrophobic or chemically interfere with cement hydration and the binder aggregate bond, particularly the interfacial transition zone (Hayes et al., 2015). High Loss on Ignition (LOI) or solvent-extractable content has been associated with reduced early strength and poorer durability in mixes containing organic-containing fines. Second, the potential for leachable trace metals or soluble salts in BHD poses environmental and regulatory questions; accordingly, characterization methods such as X-ray fluorescence/diffraction (XRF/XRD), LOI measurement and leachability screening (TCLP) are routinely recommended in recent reviews before approving industrial dusts for construction use (Bagheri et al., 2020; Hayes et al., 2015). Where BHD chemistry and LOI are favorable, blending with established SCMs (fly ash, GGBFS, silica fume) or using chemical admixtures can enable higher replacement levels while preserving or improving performance.

Despite this broader context, data specific to Nepal or to South Asia more generally are scarce. Local aggregate geology, asphalt mix formulations, fuel types and plant operating conditions can produce BHD with physical and chemical fingerprints that differ significantly from those reported elsewhere, so localized experimental programs are needed to establish practical acceptance criteria and replacement limits. Short-term mechanical indicators (slump, compressive, tensile and flexural strengths at 7 and 28 days) together with basic durability proxies (water absorption, bulk density) provide an initial, pragmatic screen for feasibility; however, a responsible pathway to field use also requires the aforementioned chemical and leachability checks plus longer-term durability tests for chloride ingress, sulfate attack and freeze–thaw where relevant. Similary, (Khadka A, 2024) examine to replace crushed brick for natural coarse aggregate in M15, M20, and M25 concrete mixes reduces compressive strength. Partial replacement, though inappropriate for structural uses, may work for non-structural applications.

The present study therefore examines BHD collected from an asphalt plant in the Pokhara Valley, Nepal, and evaluates its suitability as a partial OPC replacement in M20 concrete at nominal replacement levels of 0%, 5%, 10% and 15% by mass. The investigation measures fresh concrete workability (slump), unit weight, and hardened properties—compressive, split tensile and flexural strengths—at 7 and 28 days, and records 28-day water absorption as a practical indicator of matrix permeability. By situating the experimental findings within the existing literature on fine industrial fillers and APWP, the study aims to identify practical replacement thresholds, explain observed mechanisms (filler/packing, nucleation, binder dilution), and recommend essential characterization and mitigation steps (LOI, XRF/XRD, leachability screening, admixture use or SCM blending) required before broader adoption. The goal is to provide an evidence-based assessment that informs engineers, asphalt plant operators, and policymakers about technical potential, limitations and safe reuse practices for BHD in Nepalese concrete construction.

2. Methodology

The data collection, data analysis, and conclusions drawn from the research work can be summarized in Fig.ure 1.

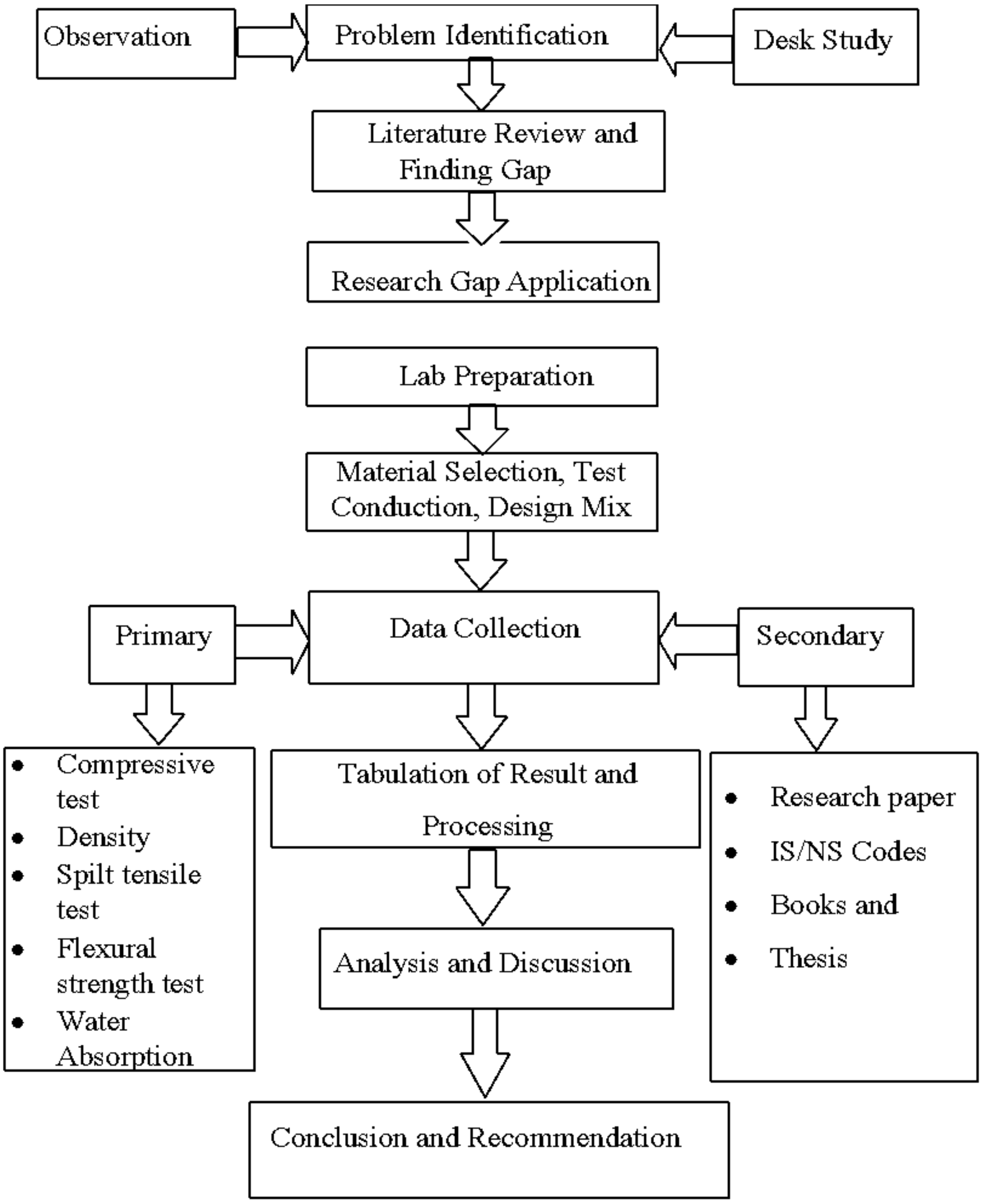

Fig. 1: Research Methodology Flow Chart

2.1 Study Design

The experimental program was developed to assess the effects of partially replacing ordinary Portland cement (OPC) with baghouse dust (BHD) from a Pokhara area asphalt plant on fresh and hardened properties of M20 concrete. The study used a fixed water to cement ratio (w/c = 0.40) to isolate binder replacement effects. Cement replacement by BHD was applied at 0% (control), 5%, 10%

and 15% by mass of cement. For each mix the total binder mass was kept approximately constant by replacing a portion of the cement mass with an equivalent mass of BHD; aggregate quantities were not changed except for moisture corrections.

Specimens and replication: for each replacement level three 150×150×150 mm cubes were cast for 7-day compressive testing and three for 28-day testing (six cubes per mix). For split tensile and flexural strength three cylinders (100×200 mm) and three beams (100×100×500 mm) per mix were prepared (tested at 28 days; 7-day tests performed where required). Three additional specimens per mix were reserved for 28-day water absorption measurements. This replication allows reporting of mean values and standard deviations for each property.

Mix design and batching: M20 target strength was used and mix proportions were calculated following IS 10262:2009 (absolute volume method) to obtain the control mix (example batch values: cement ≈ 372 kg/m3, water ≈ 186 kg/m3; report exact lab values). A laboratory pan mixer was used. Dry constituents (cement, BHD, aggregates) were dry-mixed for 2–3 minutes, water was added gradually and mixing continued another 3–5 minutes until homogenized. No chemical admixtures were used in baseline mixes.

Fresh and hardened tests: slump (IS 1199, 2018) was measured immediately after mixing. Hardened testing included compressive strength (of Indian Standards, 1959) on 150 mm cubes, split tensile strength (of Indian Standards, 1999)(IS 5816) on cylinders, and flexural strength by three-point bending on beams (IS guidance). Bulk density was calculated from specimen mass and measured dimensions at 7 and 28 days. Water absorption at 28 days was measured by oven drying (105 ± 5 °C, 24 h), 24 h immersion and calculation of percentage gain. Visual notes on workability, segregation, bleeding and failure mode were recorded for each batch.

Quality assurance and analysis: equipment (balances, molds, compression machine, ovens) were calibrated prior to testing. For each test group arithmetic mean, standard deviation and coefficient of variation were computed. Percentage change relative to control and 7/28 strength ratios were calculated.

2.2 Study Zone

The study was carried out using materials and samples representative of Pokhara Metropolitan City and the Seti Gandaki river basin. Pokhara was chosen because of rapid urbanization, ongoing infrastructure projects (roads, airport expansion, housing) and high local demand for aggregates. Local crusher plants and an asphalt mixing plant were the sources of materials:

- Baghouse dust (BHD): collected from the baghouse of a local asphalt mixing plant serving Pokhara Valley. Sampling aimed to represent routine plant production (grab samples from the active hopper in sealed containers); samples were labelled with date/time and stored dry.
- Aggregates: coarse and fine aggregates were obtained from the Bagmara crusher. The Seti-Gandaki riverbed is the principal aggregate extraction area supplying these crushers.

The study zone description included local climatic curing considerations (ambient curing water maintained at ~27 ± 2 °C), transport and handling logistics for materials, and acknowledgement that BHD composition may vary with plant operating parameters and aggregate sources typical to the region.

2.3 Data collection

Primary data collection: Representative field samples were collected and documented as follows: BHD sampling: grab samples taken from baghouse discharge or storage hopper into clean, sealed drums. Multiple sub-samples collected across production shifts where possible and homogenized in the lab to obtain the working sample.

Aggregate sampling: fresh batches of coarse and fine aggregate were collected from Bagmara using standard sampling practice to ensure representativeness. Material test data: laboratory tests on BHD, cement and aggregates produced the primary measurement dataset (specific gravity, gradation, absorption, setting times, compressive loads, etc.). Specimen test results: slump, unit weight, compressive, tensile and flexural strengths, water absorption and visual observations were recorded for each specimen and entered standardized data sheets.

Secondary data collection: Relevant standards, design guidelines and comparative literature were compiled from Department of Roads (Government of Nepal) publications, IS standards, and peer-reviewed articles on BHD and industrial filler reuse. These were used to define acceptance criteria, interpret mechanisms and to benchmark results.

Sample handling and preservation: All samples were transported in sealed containers, stored in a dry laboratory environment and labelled. BHD was dried and, when necessary, sieved to remove large contaminants before use. Aggregate moisture content was measured prior to batching and batch weights were corrected accordingly.

2.4 Material for concrete preparation

Cement: Commercial OPC 43-grade was used. Physical tests (normal consistency, initial and final setting times, fineness) were performed per IS 4031(of Indian Standards, 1996) and recorded to confirm suitability.

Baghouse dust (BHD): BHD was characterized by visual inspection (color, odor), specific gravity (pycnometer), and particle size distribution by dry sieving; where available, laser granulometry data were noted. BHD was dried, passed through appropriate sieves to remove extraneous coarse particles and stored in sealed drums.

Fine aggregate (sand): River sand from Bagmara (Zone II) was used. Tests performed: sieve analysis (of Indian Standards, 1963b)(IS 2386), specific gravity, fineness modulus, bulking, and water absorption. Sand was stored in covered bins and surface moisture measured before batching.

Coarse aggregate: Crushed gravel (20 mm nominal) from local crushers. Tests performed: sieve analysis, specific gravity, water absorption, Los Angeles Abrasion Value, Aggregate Crushing Value and Aggregate Impact Value (of Indian Standards, 1963c)(IS 2386). Coarse aggregate was free of deleterious materials and graded to IS recommendations.

Water: Potable tap water from a single local supply was used for batching and curing. Water quality was not chemically analysed in this study; consistent use minimized variability across batches.

3. Results and Discussion

The experimental results obtained from the tests conducted on aggregate, cement, and concrete specimens are presented. The results include physical and mechanical properties of aggregates, characteristics of cement, and properties of both fresh and hardened concrete. The laboratory investigations were carried out as per the relevant IS codes and Department of Roads (DoR) guidelines. The results have been analyzed and compared with standard specifications and previous research findings to evaluate the performance of Baghouse Dust (BHD) in concrete.

3.1 Test Result of Aggregate

The properties of the coarse and fine aggregates were determined to assess their suitability for concrete production. The particle size distribution was determined using sieve analysis according to IS: 2386 (Part I) – 1963(of Indian Standards, 1963a), while specific gravity, water absorption, and bulking of sand were evaluated as per IS: 2386 (Part III & IV) – 1963(of Indian Standards, 1963b, 1963c). The results are summarized in Table 1.

Table 1: Physical and Mechanical Properties of Aggregates

Property	Fine Aggregate (Sand)	Coarse Aggregate	Standard Limit (IS/DoR)
Specific Gravity	2.64	2.682	2.5 – 2.9
Fineness Modulus (FM)	3.161	7.22	
Water Absorption (%)	0.2	1.02	≤ 2.0

The sieve analysis confirmed that both coarse and fine aggregates met the grading requirements of IS 383:1970 and fell within Zone II for fine aggregates. The specific gravity of the coarse aggregate was found to be 2.682, while that of the fine aggregate was 2.64. Both values lie within the standard range of 2.5–2.9 as recommended by IS: 2386 and the Department of Roads (DoR) specifications. These values indicate that the aggregates possess adequate density and are suitable for producing normal-weight concrete. The close proximity of specific gravity between coarse and fine aggregates also ensures uniform particle packing and minimizes segregation during mixing.

The fineness modulus (FM) of the coarse aggregate was obtained as 7.22, which confirms that the aggregate is well-graded and appropriately coarse for use in structural concrete. A well-graded aggregate ensures better interlocking between particles and enhances the strength and stability of the concrete mix. The fine aggregate exhibited a fineness modulus of 3.161, which places it within the acceptable range for Zone II grading as per (IS 383, 2016). Zone II sand provides a balanced combination of strength and workability, making it ideal for general-purpose concrete.

The water absorption values were measured as 1.02 % for coarse aggregate and 0.2 % for fine aggregate, both of which are well within the standard limit of 2 %. Lower water absorption indicates that the aggregates are dense, less porous, and unlikely to significantly affect the water–cement ratio during concrete mixing. This contributes to improved durability and reduced permeability of the hardened concrete.

3.2 Test Result of Cement

Ordinary Portland Cement (OPC) of 43-grade was used for all concrete mixes. The tests for setting time, fineness, and compressive strength were conducted as per IS: 4031 (Parts IV–V) – 1988 and compared with the requirements of the Nepal Standards (NS). The results are presented in Table 2.

Table 2: Properties of Cement

Property	Test Result	Standard Limit (NS / IS)
Consistency (%)	27.3	≤ 35
Fineness (%)	5.4	≤ 10
Initial Setting Time (min)	55	≥ 45
Final Setting Time (min)	250	≤ 600

The standard consistency of the cement was found to be 27.3 %, which is well below the maximum permissible limit of 35 %. This indicates that the cement requires a normal amount of water to achieve the standard consistency necessary for proper hydration and workability. The consistency value also suggests that the cement is neither excessively dry nor overly fine, ensuring good mixability and setting performance.

The fineness of cement was measured as 5.4 % residue, which lies within the allowable limit of 10 %. Fineness directly affects the rate of hydration and strength development in concrete. The obtained value confirms that the cement particles are sufficiently fine to promote adequate early strength without causing excessive water demand or shrinkage.

The initial setting time of 55 minutes exceeds the minimum requirement of 45 minutes, indicating that the cement remains workable for a suitable duration during mixing, placing, and compaction. This provides adequate time for transportation and finishing operations before the concrete begins to stiffen.

The final setting time was recorded at 250 minutes, which is well within the prescribed limit of 600 minutes. This demonstrates that the cement hardens at an appropriate rate, ensuring timely strength gain without premature setting or delayed hardening issues.

Overall, all test results meet the requirements of NS and IS standards, confirming that the cement used in this research is of good quality and suitable for concrete production. The results also imply that the hydration characteristics of the cement will provide adequate strength development and durability in Baghouse Dust–modified concrete.

3.3 Properties of Fresh Concrete

3.3.1 Workability (Slump Test)

The workability of concrete was evaluated using the slump test according to IS 1199 (1959). The measured slump values for concrete mixes containing 0 %, 5 %, 10 %, and 15 % BHD are presented as shown in Fig.ure. The control mix (0 % BHD) exhibited the highest slump value of 75 mm, which gradually decreased to 72 mm, 68 mm, and 63 mm for 5 %, 10 %, and 15 % replacement levels, respectively in Fig.ure 2.

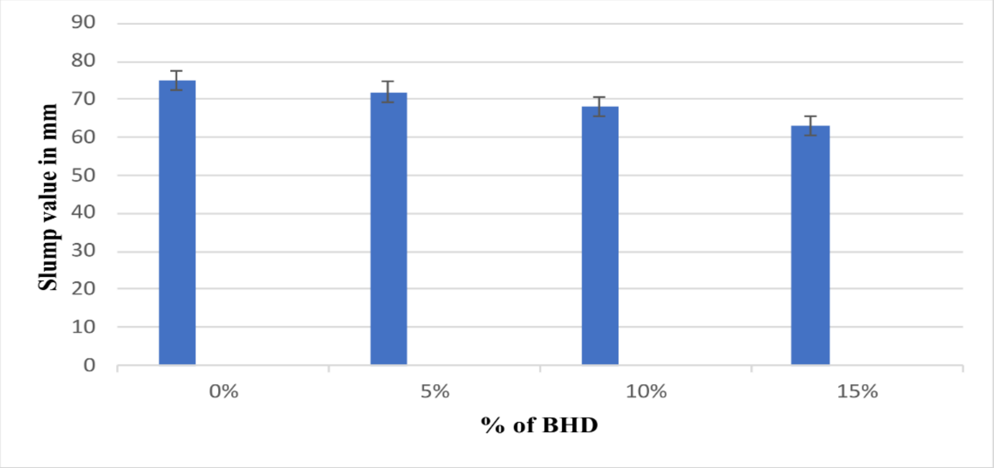

Fig. 2: Slump Value Vs % of BHD

This declining trend indicates that the introduction of BHD reduces the workability of fresh concrete. The decrease may be attributed to the high fineness and large surface area of BHD particles, which increase the water demand of the mix. Since the water-to-cement ratio was kept constant (0.40), the effective amount of free water available for lubrication decreased with higher BHD content. Similar observations have been reported by (Chaiyaput et al., 2022), who found that finer industrial by-products tend to reduce slump due to greater water adsorption.

Although workability declined, all measured slump values remained within the medium-workability range (25–75 mm as per (IS 456, 2000)), suitable for normal concreting operations. Thus, the reduction in slump does not adversely affect the placing and compaction of BHD-modified concrete provided adequate vibration is used.

3.3.2 Density

The measured densities of the concrete mixes at 7 and 28 days illustrated in Fig.ures 3,4 and 5. At 7 days, the control mix recorded an average density of 2579 kg/m³, while the 5 %, 10 %, and 15 % BHD mixes achieved 2536, 2534, and 2517 kg/m³, respectively. At 28 days, the densities were 2583 kg/m³ (control), 2567 kg/m³ (5 %), 2558 kg/m³ (10 %), and 2536 kg/m³ (15 %).

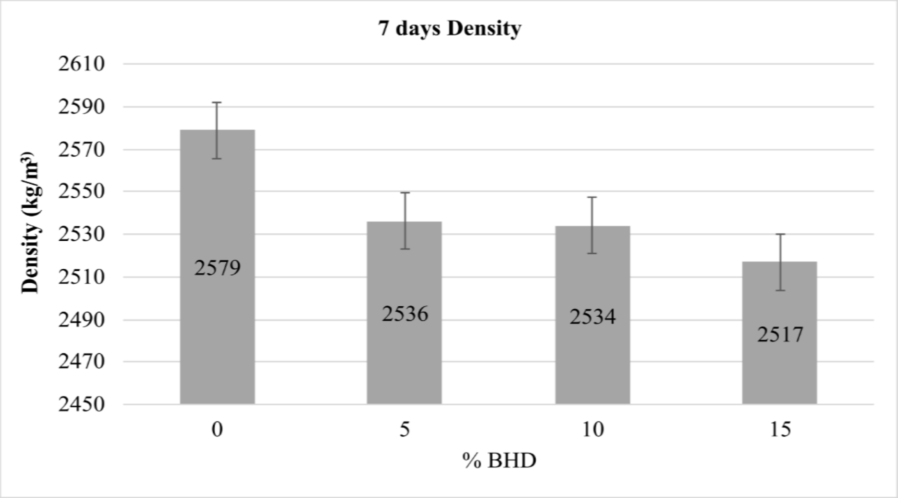

Fig. 3: Density at 7 days Vs % BHD

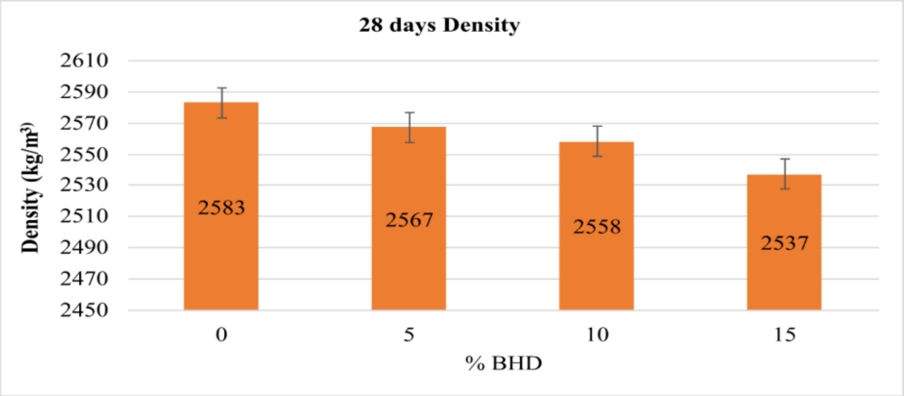

Fig. 4: Density at 28 days vs %BHD

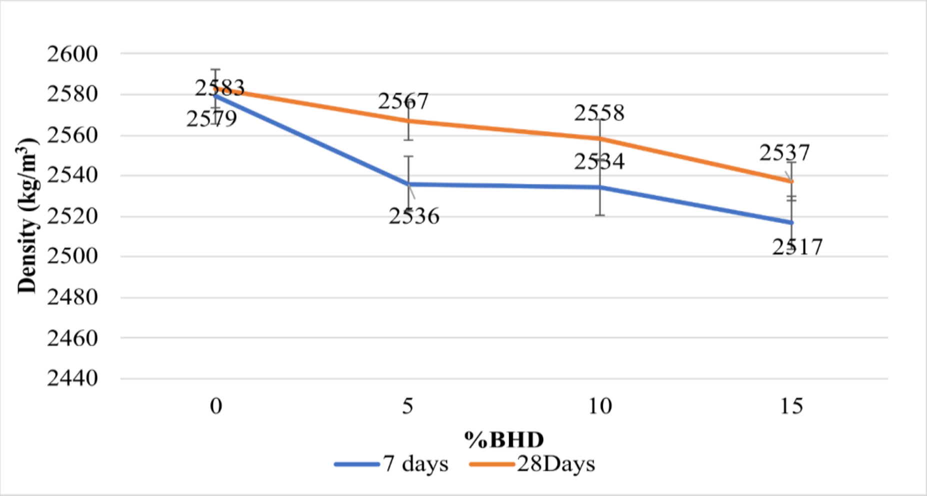

Fig. 5: Density at 7 and 28-days vs % BHD

The data show a gradual decrease in density with increasing BHD content, with a maximum reduction of about 2–2.5 % at 15 % replacement. This decrease is mainly due to the lower specific gravity of BHD (2.3) compared with OPC (3.15) and the possibility of slight air entrapment caused by the finer particles. Similar reductions in unit weight have been noted by (Hong & Choudhury, 2024) and (Ozioko & Eze, 2025), who reported that replacing denser cement with lightweight industrial fines marginally lowers bulk density. Despite the decline, all values remain within acceptable ranges for normal-weight concrete, confirming that BHD replacement up to 15 % does not significantly alter concrete compactness.

3.3.3 Water Absorption Test

Water absorption tests were performed after 28 days of curing to assess the permeability characteristics of the concrete mixes. Fig.ure 6 show average absorption values of 1.50 %, 1.63 %, 1.65 %, and 1.76 % for 0 %, 5 %, 10 %, and 15 % BHD, respectively.

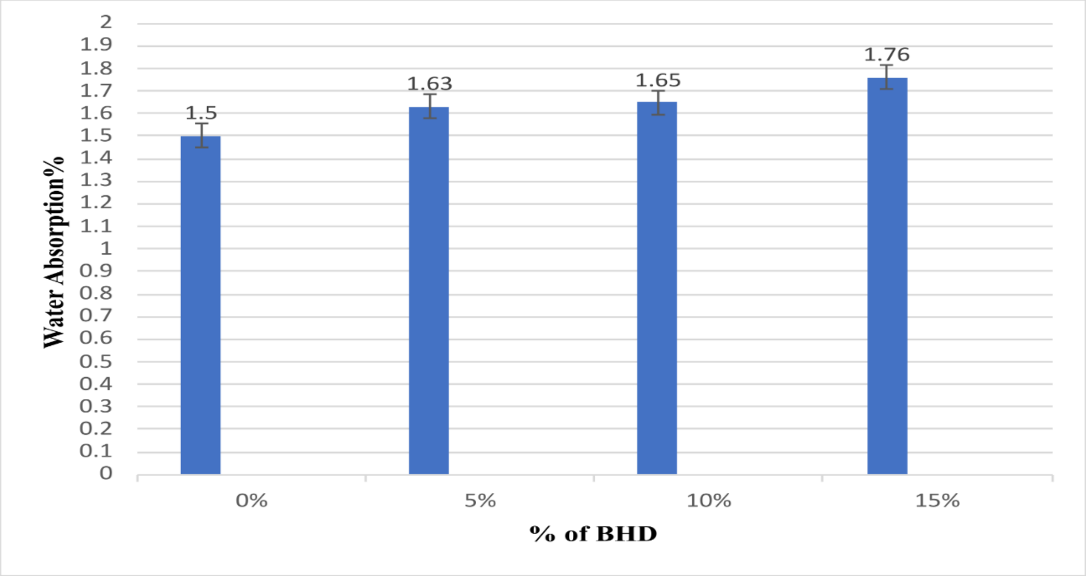

Fig. 6: Water Absorption % vs % BHD

The findings demonstrate a gradual increase in water absorption with higher BHD content. The slight rise in absorption up to 10 % replacement may be due to finer particle packing and micro-pore refinement, while the increase at 15 % is likely caused by binder dilution and increased capillary porosity. Comparable results were reported by (Golewski, 2023) and (Al-Tersawy et al., 2023), who found that industrial waste fillers raise water absorption beyond their optimum dosage due to incomplete hydration and higher pore connectivity.

Hence, it is evident that BHD content beyond 10 % adversely affects the microstructure of the concrete by increasing its porosity and reducing durability. Nevertheless, the observed absorption values are within the allowable limit for normal-weight concrete (< 5 % as per ASTM C642), demonstrating that moderate BHD use does not significantly deteriorate permeability.

3.3.4 Compressive Strength

The compressive strength test was carried out in accordance with IS 516 (1959) using 150 mm cubes. The results at 7 and 28 days are shown in Fig.ure 7. At 7 days, the control mix achieved 22.26 MPa, whereas 5 %, 10 %, and 15 % BHD mixes yielded 26.58, 23.34, and 18.52 MPa, respectively. At 28 days, the corresponding strengths were 32.29 MPa (control), 36.79 MPa (5 %), 35.23 MPa (10 %), and 30.72 MPa (15 %).

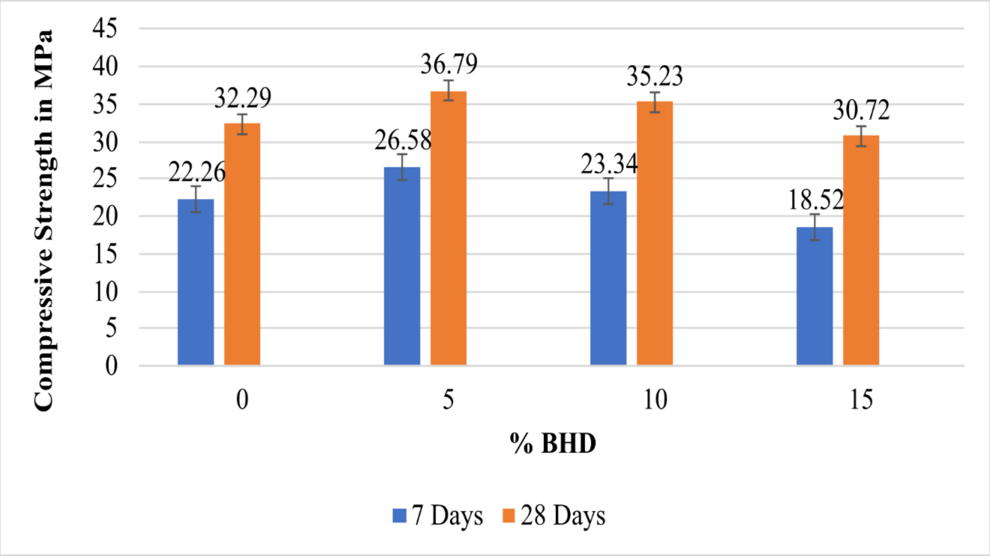

Fig. 7: Compressive Strength at 7 and 28-days vs % BHD

The maximum compressive strength was observed at 5 % replacement, recording 36.79 MPa, which is about 14 % higher than the control mix. The enhancement in strength at low replacement levels can be attributed to the filler effect of BHD particles, which fill the micro-voids between cement grains, increasing particle packing and reducing capillary porosity. Additionally, fine BHD particles act as nucleation sites for C–S–H gel formation, accelerating early hydration.

However, at higher replacement levels (≥ 10 %), the strength begins to decline due to binder dilution and possible presence of unburnt hydrocarbons that hinder hydration. At 15 %, the compressive strength dropped below the control value by 4.9 %, indicating that the reduction in cementitious material and increased porosity dominate the beneficial filler effect. Similar findings were reported by (Jahami et al., 2023) and (Miah et al., 2023), who concluded that optimum performance is achieved at low substitution levels of industrial dusts. Therefore, a 5–10 % BHD replacement is considered optimum for compressive strength development in M20 concrete.

3.3.5 Flexural Strength Test

Flexural strength results for 7 and 28 days are depicted in Fig.ure 8. At 7 days, the control mix recorded a mean flexural strength of 4.29 MPa, while the 5 %, 10 %, and 15 % BHD mixes achieved 5.12, 4.03, and 3.44 MPa, respectively. At 28 days, the corresponding values were 6.12 MPa (control), 9.68 MPa (5 %), 8.48 MPa (10 %), and 6.72 MPa (15 %).

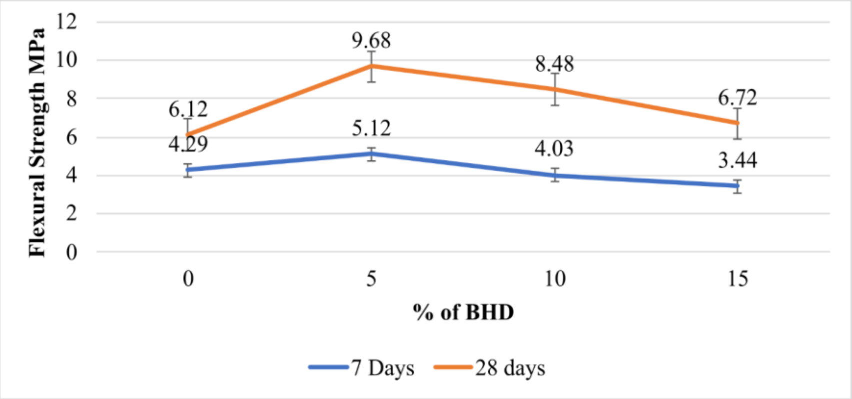

Fig. 8: Flexural Strength at 7 days and 28 days vs % BHD

The highest flexural strength was obtained at 5 % BHD replacement, showing an improvement of approximately 58 % over the control mix. This enhancement is attributed to the improved microstructural integrity and stress transfer within the cement matrix resulting from the densified interface between paste and aggregate. At higher replacement levels, the reduction in cementitious content weakens the bonding matrix and increases porosity, leading to lower flexural capacity. The trend observed here is consistent with Byrd et al. (2023) and Silva et al. (2023), who reported that fine industrial powders enhance flexural performance at small dosages (4–8 %) but reduce it beyond optimum levels. Hence, the use of 5–10 % BHD can be considered beneficial for improving flexural behavior of concrete.

3.3.6 Split Tensile Strength Test

The split tensile strength of concrete was determined on 100 mm × 200 mm cylindrical specimens as per IS 5816 (1999). The results, given in Fig.ure 9, show that at 7 days the control mix achieved 2.14 MPa, whereas 5 %, 10 %, and 15 % BHD mixes yielded 2.57, 2.32, and 1.97 MPa, respectively. At 28 days, the values were 3.06 MPa (control), 3.09 MPa (5 %), 3.20 MPa (10 %), and 2.96 MPa (15 %).

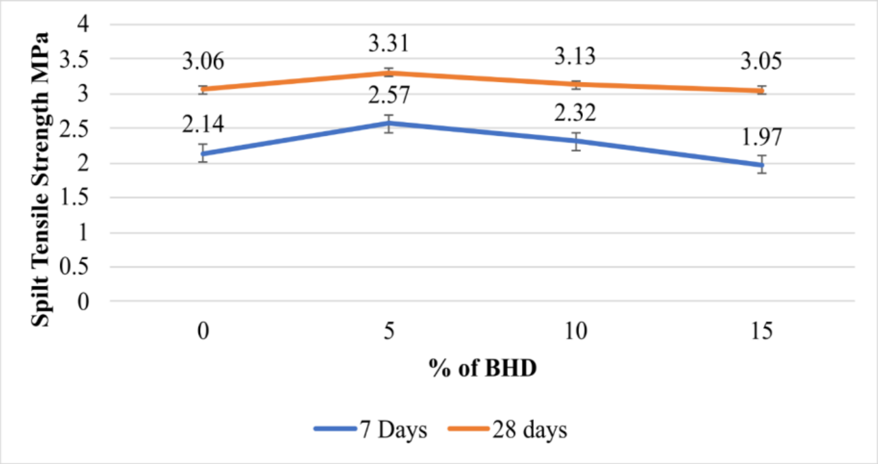

Fig. 9: Tensile Strength at 7 days and 28 days vs % BHD

The 5 % BHD mix again produced the best overall performance, with about 8 % improvement over the control at 28 days. This enhancement may be due to the filler effect and better interfacial bonding between the paste and aggregate. Higher replacements (≥ 15 %) caused a reduction in tensile strength, mainly because of cement dilution and micro-crack development at the interfacial transition zone. Similar behavior has been observed by (Kaish et al., 2021), who found that BHD replacement up to 6–8 % increased tensile strength by about 12 %, whereas further increase caused strength decline. Therefore, an optimum replacement of about 5–10 % is suggested for maintaining adequate tensile capacity in BHD-modified concrete.

4. Conclusion

This study evaluated the feasibility of using baghouse dust (BHD) from asphalt plants as a partial substitute for ordinary Portland cement (OPC) in concrete, at replacement levels of 5%, 10%, and 15% by weight. The primary aim was to investigate how BHD influences the fresh properties, mechanical strength, and durability-related features of concrete. Results indicated that adding BHD caused a gradual reduction in workability, with the slump decreasing from 75 mm in the control mix to 63 mm at 15% replacement. This is due to the decrease in cementitious material and the increase in fine particles, which together reduce fluidity. A slight decrease in density, of up to about 2.5%, was also observed as BHD content increased, likely because lighter dust particles replaced denser cement and more trapped air was introduced. Concerning mechanical performance, the best results appeared within the 5–10% replacement range. The 5% BHD mix exhibited the highest compressive strength, with a 19% increase at 7 days and a 14% rise at 28 days compared to the control, indicating improved particle packing and potential microstructural enhancements at lower dosages. Strengths declined beyond 10% replacement, probably due to binder dilution and increased porosity. Similar trends were observed in split tensile and flexural strengths, with the 5% BHD mix showing the greatest improvements, thanks to better interfacial bonding and a denser internal structure.

Overall, the findings demonstrate that BHD can be safely and effectively used as a partial cement replacement of up to 10% without compromising key mechanical or durability properties. This application not only reduces cement consumption but also promotes sustainable building practices through the beneficial reuse of industrial byproducts. For replacement levels above 10%, additional modifications such as chemical activation or combining with pozzolanic additives might be necessary to minimize strength and durability losses.

Author Contribution

Anu Adhikari conducted the experiments, performed the initial analysis, data analysis (SPSS Amos) and wrote the original draft. Bishwash Poudel contributed to result validation. Om Praksh Giri and Rajendra Aryal conceptualized the work and Sundar Adhikari supervised the work, and also provided overall guidance, and finalized manuscript.

Conflicts of Interest

The authors declare no conflict of interest

References

Al-Tersawy, S. H., Zakey, S. E., El-Sadany, R. A., & Sallam, H. E. D. M. (2023). Utilization of Various Industrial Wastes in Ordinary Concrete Under Normal Manufacturing Conditions. *International Journal of Concrete Structures and Materials 2023 17:1, 17*(1), 44-. https://doi.org/10.1186/s40069-023-00603-6

Bagheri, S. M., Koushkbaghi, M., Mohseni, E., Koushkbaghi, S., & Tahmouresi, B. (2020). Evaluation of environment and economy viable recycling cement kiln dust for use in green concrete. *Journal of Building Engineering*, *32*, 101809. https://doi.org/10.1016/j.jobe.2020.101809

Chaiyaput, S., Sertsoongnern, P., & Ayawanna, J. (2022). Utilization of Waste Dust from Asphalt Concrete Manufacturing as a Sustainable Subbase Course Material in Pavement Structures. *Sustainability 2022, Vol. 14, Page 9804*, *14*(16), 9804. https://doi.org/10.3390/su14169804

Golewski, G. L. (2023). Assessing of water absorption on concrete composites containing fly ash up to 30 % in regards to structures completely immersed in water. *Case Studies in Construction Materials*, *19*(2), e02337. https://doi.org/10.3390/buildings12020192

Hayes, J. B., Wang, J., Roessler, J. G., Ferraro, C. C., Wu, C. Y., Deford, D., & Townsend, T. G. (2015). Evaluation of leaching of trace metals from concrete amended with cement kiln baghouse filter dust. *Resources, Conservation and Recycling*, *94*, 92–98. https://doi.org/10.1016/j.resconrec.2014.11.012

Hong, Y. M., & Choudhury, S. R. (2024). The Substitution Effect of the Fine Aggregate in Concrete with Oyster Shell. *Materials 2024, Vol. 17, Page 6148*, *17*(24), 6148. https://doi.org/10.3390/ma17246148

I, T. Joshua., Apata, A. C., & Dawodu, P. O. (2024). An Evaluation of Mechanical Behaviors of Baghouse Dust in Asphalt Concrete Mix Using Discrete Element Method (DEM). *Journal of Engineering Research and Reports*, *26*(7), 278–284. https://doi.org/10.9734/jerr/2024/v26i71208

IS 383. (2016). *IS 383 : 2016 Coarse and Fine Aggregate for Concrete - Specification (Third Revision).*

IS 456. (2000). *IS 456 : 2000 PLAIN AND REINFORCED CONCRETE - CODE OF PRACTICE (Fourth Revision).*

IS 1199. (2018). *IS 1199 : Part 1 : 2018 Methods of Sampling, Testing and Analysis Part 1 Sampling of Fresh Concrete (First Revision).*

Jahami, A., Younes, H., & Khatib, J. (2023). Enhancing Reinforced Concrete Beams: Investigating Steel Dust as a Cement Substitute. *Infrastructures 2023, Vol. 8, Page 157*, *8*(11), 157. https://doi.org/10.3390/infrastructures8110157

Kaish, A. B. M. A., Odimegwu, T. C., Zakaria, I., & Abood, M. M. (2021). Effects of different industrial waste materials as partial replacement of fine aggregate on strength and microstructure properties of concrete. *Journal of Building Engineering, 35,* 102092. https://doi.org/10.1016/j.jobe.2020.102092

Khadka A, T. P. A. S. (2024). Comparative Analysis of Compressive Strength of Natural and Brick Aggregate Concrete. Journal of UTEC Engineering Management, 2(01), 1–11. https://doi.org/10.36344/utecem.2024.v02i01.001

Mehta, P. K., & Monteiro, P. J. M. (2006). CONCRETE Microstructure, Properties, and Materials. *Concrete: Microstructure, Properties, and Materials*, 10–14. https://repositori.mypolycc.edu.my/jspui/handle/123456789/4614

Miah, M. J., Huaping, R., Paul, S. C., Babafemi, A. J., & Li, Y. (2023). Long-term strength and durability performance of eco-friendly concrete with supplementary cementitious materials. *Innovative Infrastructure Solutions 2023 8:10*, *8*(10), 255-. https://doi.org/10.1007/s41062-023-01225-3

of Indian Standards, B. (1959). *IS 516 (1959): Method of Tests for Strength of Concrete*.

of Indian Standards, B. (1963a). *IS 2386-1 (1963): Methods of Test for Aggregates for Concrete, Part I: Particle Size and Shape*.

of Indian Standards, B. (1963b). *IS 2386-3 (1963): Methods of test for aggregates for concrete, Part 3: Specific gravity, density, voids, absorption and bulking*.

of Indian Standards, B. (1963c). *IS 2386-4 (1963): Methods of test for aggregates for concrete, Part 4: Mechanical properties*.

of Indian Standards, B. (1996). *IS 4031-1 (1996): Methods of physical tests for hydraulic cement, Part 1: Determination of fineness by dry sieving*.

of Indian Standards, B. (1999). *IS 5816 (1999): Method of Test Splitting Tensile Strength of Concrete*.

Ozioko, H. O., & Eze, E. E. (2025). Evaluating the impact of demolished concrete aggregates on workability, density, and strength with predictive modeling. *Discover Civil Engineering 2025 2:1*, *2*(1), 68-. https://doi.org/10.1007/s44290-025-00230-y

Razak, R. A., Zulkifli, Z., Abdullah, M. M. A. B., Yahya, Z., Mydin, M. A. O., Ishak, S., Nabiałek, M., & Jeż, B. (2025). Utilization of asphalt plant waste powder as a partial cement replacement in concrete. *Archives of Civil Engineering*, *Vol. 71*(nr 2), 491–501. https://doi.org/10.24425/ace.2025.154133