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SUSTAINABLE INVESTIGATION ON POND ASH-INDUCED COMPRESSED INTERLOCKING BRICKS

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Abstract

Investigating the sustainability of using pond ash in compressed interlocking bricks is a multi-faceted process that requires assessing environmental, economic, and social aspects. India churns out more than 200 million tonnes of untapped coal ash every year. Stone crusher plants and thermal power plants are exhibiting huge amounts of unutilized by-products which have started invading our environment negatively and could soon create hazardous impacts. This paper focuses on investigating a new emerging sustainable brick constituting all these waste substances. Unutilized stone dust from crushers of the Khordha Industrial Area and Ash (Pond ash and Fly ash) were collected from the NALCO Power Plant situated at Angul, Odisha, India. Pond ash Induced Compressed Interlocking Bricks (PAICIB) were fabricated having parent mix with pond ash & fly ash levels of 35% and 40% stone dust by weight, which was fixed after several trial mix experiments. Variation was done with the proportion of lime and cement to the parent mix. Compressive strength tests were conducted on day 7 and 28. The parent mix of 30cmx15cmx10cm PAICIB containing no cement and 10% hydrated lime by weight of parent mix sustained a compressive strength up to 5.5 N/mm^2 (failure load of 204KN) and the water absorption was 17% after 28 days. The primary focus of this investigation is to utilize the waste materials for creating an eco-friendly brick that can meet the demand of the current rising population of populated countries like India. This work becomes a part of the "fly ash management and utilization mission" by NGT as the bricks are formed here using the disposed pond ash in rivers reducing water pollution too.

Keywords : CIB, Failure load, Fly ash management, Parent mix, Pozzolona,.

I. Introduction

Developing cities have surged the population very rapidly in recent times exponentially. The housing industry and transportation have elevated the need for the construction world. Waste disposal techniques are the immediate need for making construction works effective and economical (Saravanan and Balamuralikrishnan,2021). Hence we should focus more on utilizing byproducts such as pond ash, fly ash, and quarry dust as an alternative to conventional materials(Bhavsar et. al, 2022). After China, India is the 2nd highest generator of power from coal. The output capacity of thermal power plants has increased over the recent years. According to an annual report published by the Central Electricity Authority, Ministry of Power, Government of India, 232.56 million tonnes of fly ash was generated during 2020–2021 and only 13% of ash is utilized for the ash industry. Fly ash is a finely divided residue produced from the coal combustion process (Verma.et.al,2016). Despite continuous efforts to increase the utilization rate, the government still does not achieve 100% utilization (Thanoon et. al, 2004). Particle size differentiate fly ash and pond ash from each other. Boilers spell out pond ash as its by-product where steam is prepared by igniting coal in thermal plants. The fly ash along with bottom ash is disposed of in large ponds as slurry. This is known as an ash pond and the particles are coarser. (Sonawane and Dwivedi,2013).

Table 1: Chemical Composition of Fly ash & Pond Ash (Sonawane and Dwivedi,2013)

Constituent	Fly ash (%)	Pond ash (%)
SiO_2	49 – 67	67.4
Al_2O_3	16 – 29	19.44
Fe_2O_3	4 – 10	8.5
CaO	1 – 4	2.7
MgO	0.2 – 2	0.45
SO_3	0.1 – 2	0.3

The interlocking system is a new concept to make masonry construction more economical and faster compared to conventional masonry construction which has mortar joints. (Khan and Deshmukh,2015). Interlocking bricks are unique in relation to conventional bricks since the absence of the mortar to be filled between the brick layers during the construction process. Curing and plastering are not needed in Interlocking Brick (IB)(Jafaar.et.al,2006). Interlocking brick is economical. Instead of using nominal brick, interlocking brick can be used as it saves costs in terms of cement, sand, and water. Interlocking bricks are subjected to less damage when compared with a nominal brick during an earthquake (Safiee. et. al 2011). Building walls and partitions are formed sooner. The requirement of skilled labor is very low in Interlocking bricks as bricks here are stacked on one another. Homogeneous layers in interlocking wall systems lead to effective load transfer and hence strength was higher in the case of interlocking walls than in conventional masonry (Dhanraj.et.al,2019)

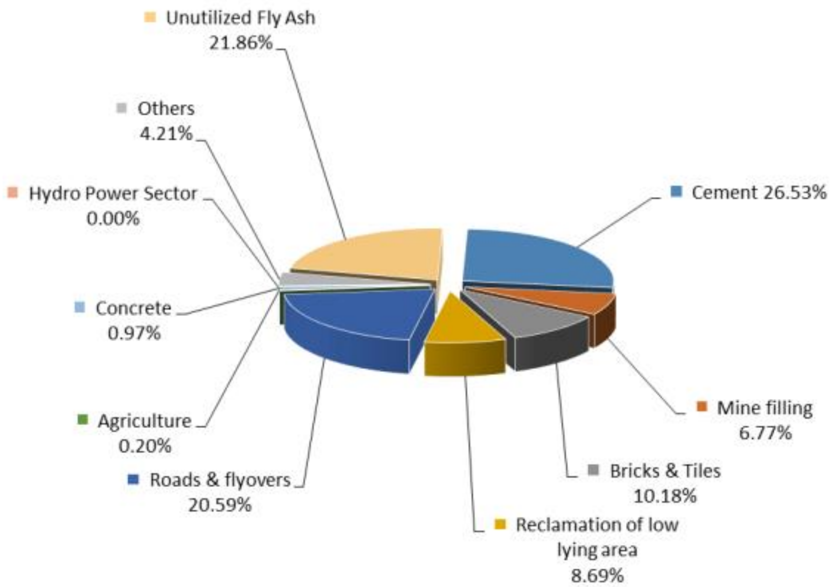

Fig. 1. Fly Ash Utilization, Source: CEA Report, New Delhi, 2022-23

II. Literature Review

Research and studies are still in process for effective disposal and several strategies have been developed to control the environmental hazards (Romeekadevi.et.al,2015) of Ash but still majority of it is still not utilized properly (Sarkar et. al, 2007). Huge areas and acres of land employed for this purpose remains blocked which could have been used for agro or other purposes (Ghosh. et. al 2014). The use of Fly ash has elevated to 92% in 2020-2021 over the previous ten years as a result of government regulations and public awareness. Fly ash being pozzolanic can be implemented as a replacement in mortar or concrete which can improve durability and strength (Bazzar. et. al, 2021). However, pond ash has a lower pozzolanic index which doesn't allow it to provide good strength like fly ash. Pond ash doesn't elevate the strength performance much as per earlier studies. The most significant among all are uses in the construction of road embankments (Rath and Shirish,2017), pavements, the building industry, and the cement industry (Sarkaret. al, 2017). Quarry dust on the other hand has nearly the same specific gravity as sand (Prakash and Rao, 2017) and has issues of disposal near crusher plants can substitute sand in various areas like bricks, and concrete for constructing roads, buildings, and bridges

(Shafabaksh.et.al,2016) and inclusion of quarry dust enhances the workability. Various research on adding waste and byproducts like Rice Husk ash, Lime, Silica, Rubber Crumps, Geopolymer, and Waste marble powder was added to enhance the engineering properties of conventional bricks and interlocking bricks. Strength, Water absorption, ductility, and many other tests were conducted on Interlocking bricks. In-Plane and Out-Plane tests were conducted on Conventional brick walls and Interlocking brick walls to investigate the Seismic response of the wall. Many investigations are still in process for utilizing waste materials like pond ash in the form of bricks to reduce river pollution and save the land which is being used for disposal unnecessarily.

The current state of research regarding the utilization of industrial byproducts and waste materials, such as fly ash, pond ash, and quarry dust, in construction applications. Here's a breakdown and expansion on the points you've raised:

- **Fly Ash Utilization**:
    - Fly ash, due to its pozzolanic properties, has seen significant utilization in mortar and concrete production, contributing to improved durability and strength.
    - Government regulations and increased public awareness have driven the utilization of fly ash, with its usage increasing up to 92% in recent years.
- **Pond Ash Challenges**:
    - Unlike fly ash, pond ash has a lower pozzolanic index, limiting its ability to enhance strength in construction materials like mortar and concrete.
    - Previous studies have shown that pond ash does not significantly improve strength performance compared to fly ash.
- **Applications of Pond Ash**:
    - Despite its limitations, pond ash finds applications in construction, particularly in road embankments, pavements, and the cement industry.
    - Challenges remain in effectively utilizing pond ash due to its lower pozzolanic index and limited strength-enhancing properties.
- **Quarry Dust as a Substitute**:
    - Quarry dust, with properties similar to sand, can serve as a substitute in various construction applications, including bricks, concrete, roads, buildings, and bridges.

  - Its inclusion can enhance workability and provide an alternative to sand, addressing issues related to disposal near crusher plants.

- **Incorporation of Waste Materials**:
  - Researchers have explored the addition of various waste and byproducts, such as rice husk ash, lime, silica, rubber crumbs, geopolymer, and waste marble powder, to conventional and interlocking bricks to enhance their engineering properties.
  - Tests, including strength, water absorption, and ductility, have been conducted to evaluate the performance of these modified bricks.

- **Seismic Response Investigation**:
  - In-plane and out-plane tests have been conducted on both conventional brick walls and interlocking brick walls to assess their seismic response.
  - The research aims to understand how incorporating waste materials into bricks affects their structural integrity and seismic performance.

- **Environmental Impact and Land Use**:
  - Utilizing waste materials like pond ash in brick production can reduce river pollution and alleviate the need for land disposal, contributing to sustainable construction practices.
  - Continued investigation and research are crucial to developing effective strategies for utilizing waste materials in construction while minimizing environmental impact and optimizing performance.

In summary, the ongoing research aims to address challenges related to the utilization of waste materials in construction while exploring their potential benefits and mitigating environmental hazards associated with their disposal.

III. Materials

The materials used for ash blocks were fly ash, pond ash, quarry dust, lime, and cement. Class F fly ash and pond ash used for the research were procured from the NALCO Captive Power Plant in Odisha. Fly ash and pond ash were stored in plastic bags to avoid contact with moisture. On the other hand, quarry dust was purchased from the Radha Krishna crusher plant on the outskirts of the capital city of Odisha. Binding materials like hydrated lime and OPC cement were acquired locally. OPC-53 grade cement of RAMCO brand was used for the study.

Table 2: Physical properties of raw materials

Properties	Fly ash	Pond ash	Quarry dust	Cement
Colour	Light grey	Light grey	Grey	Light grey
Specific gravity	2.05	1.75	2.84	3.25
Particle shape	Spherical, non-porous	Spherical, porous	Irregular	-
Particle size	<20µm	<100µm	Up to 300µm	-

Here's a comparison of some key properties between fly ash, pond ash, quarry dust, and cement. These properties play crucial roles in determining the behavior and performance of these materials in construction applications. For example, specific gravity affects the density and weight of the material, particle shape influences packing and interlocking within concrete mixtures, and particle size distribution can impact the workability and strength of concrete mixes. Understanding these properties helps engineers and builders make informed decisions when selecting materials for specific construction projects and applications.

IV. Experimental Program

Mix Proportion

The parent mix(P) is constituted entirely of fly ash, pond ash, and quarry dust. Fly ash and pond ash together make up 70% at equal levels of the parent mixture whereas quarry dust is maintained at 30% throughout all ratios. Hydrated Lime and Cement were added to the Parent mixture with different proportions by weight. Table 3 displays the proportions considered.

Table 3 : Different mixes with Hydrated lime and Cement addition to P by weight.

Mix No.	M1	M2	M3	M4	M5	M6
Cement % By weight	0	0	1	1	0	1
Lime % by weight	7.5	10	7.5	10	5	5

P: Parent mix with Pond ash and Fly ash proportion of 35% and remaining 30% Quarry dust (All % by weight)

Mixing of raw materials

Before mixing the raw materials, it was ensured that they were oven-dried and lumps were absent to facilitate the proper formation of mortar. The quarry dust was also sieved using a 4.75 mm sieve to avoid mixing larger stones. Keeping quarry dust, lime, and cement constant, different weight ratios of fly ash and pond ash were decided. Quantities of the materials were weighed using a high-precision digital weighing balance followed by hand mixing which was done on a hard, clean and non-porous flat iron sheet plate base. The required amount of water was added to it.

Methodology and Casting of bricks

The mix after the desired amount of mixing was put in the interlocking brick machine having a mold size of 30cmx15cmx10 cm and compressed to form PAICIB. After compression, it was removed carefully and allowed for curing after 48 hours. Figure 2 shows the experimental program and interlocking brick machine used to cast the interlocking bricks.

Fig. 2(a). Interlocking Brick Machine

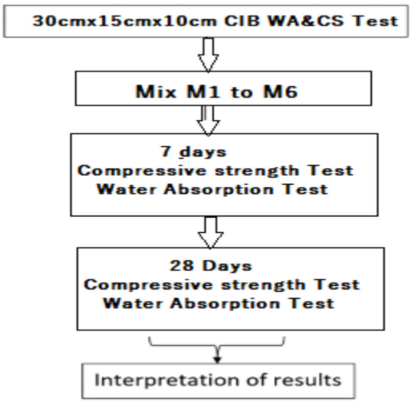

Fig 2. (b). Experimental Program

Compressive strength

The testing procedure recommended in the Indian Standard Codes of Practice for physical tests for hydraulic cement i.e. IS 4031-6 (1988) was adopted. Three specimen bricks each from the six experimental mixes were tested for compressive strength in a 2000 kN capacity compression testing machine, Figure 3(b) at the end of 7 days and 28 days. Figure 3(a), Both the surfaces of the interlocking bricks were levelled. The maximum failure load was determined for each sample and the mean was tabulated. Figure 3 (c) shows the damaged structure of the PAICIB after the compressive test.

Fig 3. (a). **Fig 3. (b).** **Fig 3. (c).**

Water absorption.

A water absorption test on the bricks was conducted after 28 days and the average was taken for each proportion in accordance with the guidelines in IS 3495 (Part 2): 1992 (Indian Standard Methods of Tests of Burnt Clay Building Bricks -

Determination of Water Absorption). The bricks were oven-dried for 24 hours before keeping another 24 hours submerged in water(Fig.4) before the test.

Fig. 4. PAICIB submerged in water pond for W/A test

V. Result and Discussion

PAICIB exhibited compressive strength in the range of 3.44 to 3.77 N/mm2 at the end of 7 days and 3.9 to 5.5 N/mm2 at the end of 28 days for M1 to M4 design mixes.M5 and M6 mixes with 5% hydrated lime by weight of the Parent mix did not bind itself and failed while fabricating the bricks in the IB machine. The failure area considered during the compressive strength test was 37225 mm2 in the case of our PAICIB after deducting the hole area present in the brick. M2 is the cementless brick with 10% hydrated lime mixed with parent mix giving a maximum failure load of 204 kN delivering a strength of 5.5 N/mm2.As per IS Code 1077:1992 and 12894:2002, bricks have been classified based on their strength from 3.5N/mm2 to 35N/mm2. Due to the acceptable strength values of bricks produced employing industrial wastes, the findings suggest minimizing the dependence on naturally occurring raw materials like clay for the manufacturing of bricks.

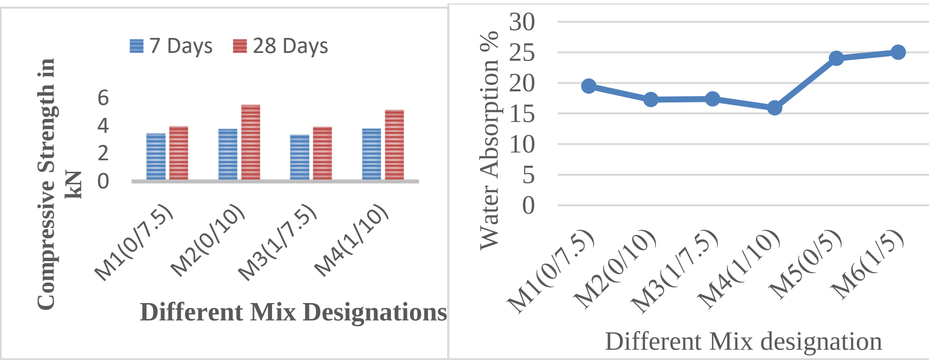

Fig.5 (a). 7&28 days Comp. Strength analysis Fig.5(b)Water Absorption 7&28 days

Fig. 5(c). M1 to M4 PAICIB

Fig.5.(d). M5/M6 PAICIB

Water Absorption of each mix was determined and the average values of three bricks of the same proportion were recorded. Mix having the presence of cement gave slightly better results as compared to cementless bricks.10% hydrated lime addition to the parent mix improved the results. The maximum water absorption value is 20% in the case of fly ash bricks as prescribed in IS 12894:2002. The water absorption values elevated in the case of 5% hydrated lime addition to PAICIB, the results exceeded beyond 20%.

Table 4 : Mean Results of Compressive strength in N/mm2 and Water Absorption in % at 7 and 28 days

Mix No.	M1	M2	M3	M4	M5	M6
7-day compressive strength (N/mm^2)	3.44	3.77	3.35	3.77	-	-
28-day compressive strength (N/mm^2)	3.94	5.48	3.9	5.12	-	-
Water absorption (%) (28 days)	19.5	17.2	17.4	15.9	24	25

VI. Conclusion

I. The Optimization of Compressive Strength increased with the addition of 10% hydrated lime resulting in maximum compressive strength at 28 days.

II. Interestingly, the addition of 1% cement did not significantly enhance compressive strength, suggesting that the presence of hydrated lime played a more critical role in strength development.

III. The cement addition slightly improved water absorption properties, particularly up to 15% when added to the mix containing hydrated lime but with a lower amount of hydrated lime the water absorption values degraded.

IV. The strength of PAICIBs increased with an increase in the percentage of hydrated lime, with a significant improvement of up to 40% at 10% lime addition. This increase in strength was observed regardless of cement addition, indicating the effectiveness of hydrated lime as a strengthening agent.

V. The interlocking properties of PAICIBs allow for the erection of walls without mortar, resulting in rapid construction, making them suitable for temporary low-cost structures. Despite the presence of holes in the bricks, which could be utilized for reinforcement, the achieved strength was deemed ideal for construction purposes.

The study focuses on utilizing waste pond ash as a primary material, prioritizing waste utilization over strength and durability. The absence of cement in the brick formulation contributes to reducing global warming and environmental impact. Additionally, the study aligns with the "fly ash management and utilization mission" by NGT, contributing to the reduction of water pollution by utilizing disposed pond ash in rivers. In summary, the study presents a sustainable approach to brick production by utilizing waste pond ash and hydrated lime, resulting in lightweight, cement-less interlocking bricks with acceptable strength and durability. These findings have implications for low-cost construction practices and contribute to environmental sustainability initiatives.

Conflict of Interest

The authors declare that there are no conflicts of interest to disclose about the publishing of our research work in this article.

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