PARTIAL REPLACEMENT OF CEMENT WITH PAINT SLUDGE IN CONCRETE BLOCK & IT'S ENVIRONMENTAL IMPACTS

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ABSTRACT

Industrial waste may have a severe negative impact on the environment and it releases toxic components that endanger human health and ecosystems, cause major pollution, and upset sensible ecological balances. The use of industrial waste materials in concrete production has gained significant attention due to its potential to address environmental concerns and enhance sustainability. This study focuses on assessing the partial replacement of cement with paint sludge in concrete blocks and its impact on the environment. The experimental investigation involved the incorporation of paint sludge as a cement replacement material in concrete blocks at various proportions, ranging from 0% to 20% by weight. Different qualifying test (compressive strength,slump value etc) were performed to evaluate the performance of concrete. Moreover leaching test of (Cr,Si) was also performed to investigate the environment impacts of paint sludge. The study revealed that 5% replacement had the desirable effect and the results indicated that adding paint sludge had a noticeable effect on the mechanical performance of the concrete blocks. The outcome of the leaching test found that heavy metal and other pollutants were within acceptable limits, demonstrating the potential suitability of paint sludge as a cement replacement material without posing significant environmental risks. Overall, this study provides valuable insights into the feasibility of utilizing paint sludge as a partial replacement for cement in concrete block production. The findings suggest that such an approach can contribute to environmental sustainability by reducing waste generation and lowering the environmental impact associated with conventional concrete production.

Keywords: *Compressive strength, Concrete block, Heavy metal, Leaching effects, Paint sludge*

1. INTRODUCTION

Cement production, primarily reliant on carbon-intensive fuels and limestone calcination, contributes significantly to carbon dioxide (CO_2) emissions. Employing mineral or waste additions as a partial substitute for cement emerges as a viable strategy to effectively diminish the environmental footprint (Uzal & Turanli, 2003). The incorporation of waste materials such as fly ash, silica fume, or blast furnace slag as partial replacements for cement in cementitious mixes offers a potential solution to address these issues. The economic analysis of mortar incorporating waste materials at 10% and 20% replacement levels for hydrated lime and sand, respectively, demonstrates compelling results. This study reveals that substituting conventional lime in cementitious materials with industrial solid wastes could lead to substantial annual savings of approximately 250 million dollars. Such findings underscore the significant economic advantages associated with integrating industrial solid wastes into construction practices (Mayhoub et al., 2022).

Recycled crumb rubber, plastic waste, and crushed brick bring distinct attributes that augment the fire resistance, toughness, functionality, and insulation features of concrete blocks (Meng et al., 2018). This approach can result in enhanced workability, strength, and durability of cementing materials. The construction industry's rapid expansion, fuelled by extensive mining of aggregates and cement, poses environmental challenges through excessive use of natural resources, leading to environmental issues (Mo et al., 2016). In response to these environmental concerns, there is a growing interest in identifying alternative materials to replace traditional building components (Hossain et al., 2016). In the present context, agro-waste is being employed as a partial substitute for traditional materials. Notably, substantial results have been attained by incorporating materials such as bone powder ash, accounting for around 10% of the mixture (Joel, 2010). One such candidate is paint sludge, a waste product from the paint manufacturing industry. Paint sludge, with pozzolanic properties similar to cement, has the potential to serve as a sustainable cement substitute in construction applications. Some studies indicate that paint sludge can be utilized as a substitute for up to 20% (w/w) of pure bitumen in the manufacturing of hot mixture asphalts (HAMs) without compromising the technical performance of pavements (Ruffino et al., 2021). Currently, a significant portion of paint sludge undergoes incineration in specialized combustion facilities or is processed in licensed cement kilns as refuse-derived fuel (RDF) to facilitate energy recovery (Salihoglu et al., 2018). An estimated 25–30 million gallons of water-based paint are utilized annually in Bangladesh, resulting in the generation of approximately 2100 tons of paint sludge. The conventional disposal approach for paint sludge involves a sequence of physical and chemical treatments, ultimately culminating in incineration (Polprasert & Liyanage, 1996). The incorporation of paint sludge can notably extend the setting time in cement. Additionally, owing to its pozzolanic properties, paint sludge exhibits the capability to enhance the long-term strength gain in cement mortar. Furthermore, the utilization of paint sludge in concrete enhances its ability to resist sulphur attack, and concurrently reduces chloride migration (Ahmad et al., 2022).

This study aims to investigate the potential of using paint sludge as a partial substitute for cement in concrete block production. Furthermore, the study evaluates the environmental effects, particularly heavy metal leaching, contributing to sustainable construction practices and their environmental benefits.

2. MATERIALS AND METHODS

The quality of materials is greatly influenced by the methodology and testing techniques employed in the study. The accuracy of results is directly tied to the precision of the testing methods. Initially, the materials were gathered and analyzed, followed by a thorough check to ensure that the experimental values fell within permissible limits. The experimental flow diagram for compressive strength analysis and leaching test is illustrated below in Figure 1. The properties of concrete structures, including compressive, tensile, flexural strength, and toughness, depend significantly on the characteristics of the materials used. Materials properties such as Fineness modulus, Specific gravity, Unit weight, Absorption capacity, Moisture content, Consistency, Initial and final Setting time were tested by according to ASTM C136, ASTM C204, ASTM C127, ASTM C188, ASTM C29,ASTM C185, ASTM C566, ASTM C109, ASTM C191 .

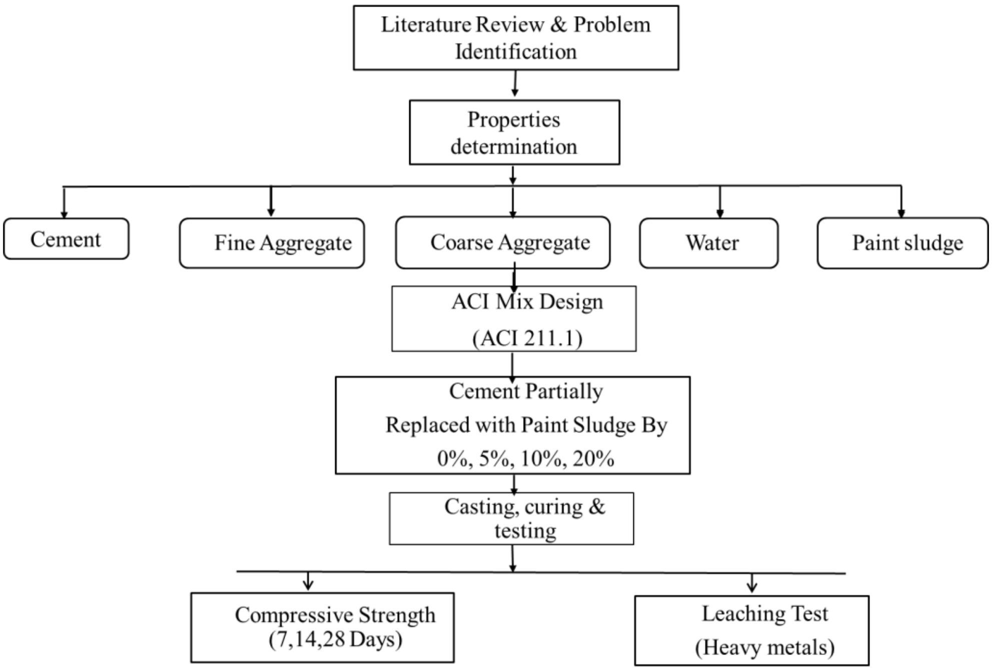

Figure 1: Step by step schematic working flow diagram aadopted for this study

The primary objective of our research is to ascertain the suitability of paint sludge as a cementitious material. Therefore, a partial replacement approach was adopted, and the specific gravity test for cement was conducted following ASTM C188. Therefore, the method employed involved testing the paint sludge used for partial replacement of cement, aligning with the ASTM C188 standard.

2.1 Concrete materials

In the experimental work conducted, stone chips were chosen for optimal results, ranging in size from 2.36 mm to 20 mm. The maximum size of coarse aggregates in this study was set at 20 mm. In the examination of fine aggregate, natural sand passing through a 4.75mm sieve was utilized, exhibiting a specific gravity of 2.62. In this context, the specific gravity of well-graded sand is conventionally considered to range between 2.5 and 2.9. Ordinary Portland Cement (OPC) was employed in the mentioned study, specifically Seven Rings Cement. The initial setting time and final setting time were observed to be 30 minutes 6 hours 20 minutes, respectively.

2.2 Concrete mix design and leaching test

A concrete mix design was carried out for 41 MPa according to the ACI 211.1, 2009 Mix design. Afterward, forty-five (45) concrete blocks were cast and submerged in water for curing periods of 7, 14, and 28 days. The leaching test of the cubes was then performed in parallel, and both the compressive strength data and leaching results were analyzed. Following multiple laboratory trials, the concrete mix ratio was found as Cement: FA: CA= 1:0.86:1.62 with a water-cement ratio of 0.32.

2.2.1 Testing procedure

Compressive strength test

In the experimentation process, two sets of concrete samples were prepared to evaluate the impact of partial replacement of paint sludge in comparison to no replacement. For the zero percent partial replacement, three cubic samples labelled as S1, S2, and S3 were created, totalling nine cubes. These cubes, with dimensions of 100 mm × 100 mm × 100 mm, underwent compressive strength testing at 7 days, 14 days, and 28 days of curing. In contrast, for partial replacements of 5%, 10%, and 20%, four cubic samples were prepared for each replacement level, resulting in a total of 12 molds. From each mold, three cubic samples were taken, yielding a total of 27 samples. These samples, sharing the same dimensions as those in the zero percent replacement group, underwent compressive strength testing at the same curing intervals. Additionally, the experimentation extended beyond compressive strength testing to include heavy metal leaching tests. The remaining nine samples, likely from the zero percent replacement group, underwent heavy metal tests. This comprehensive approach aimed to assess both the mechanical properties and environmental implications of the concrete blocks with and without paint sludge replacement. In summary, a total of 45 cubic blocks were manufactured to facilitate the experimental work and subsequent result analysis. Among these, 36 blocks were allocated for partial replacement scenarios (5%, 10%, and 20%), while the remaining 9 blocks served as a control group with no paint sludge replacement. This multifaceted experimental design enables a thorough investigation into the mechanical and environmental aspects of the concrete blocks, providing valuable insights into the potential benefits or drawbacks of incorporating paint sludge as a partial substitute in the construction material.

(a) (b)

Figure 2: (a) Casting of Concrete Blocks with Various Partial Replacements, (b) Compressive Strength Test of Cubic Blocks

Leaching test for metallic concentration

The tank leaching test for heavy metal extraction from water is a laboratory procedure utilized to assess the potential of extracting heavy metals from water through a tank leaching process. This test primarily involves exposing a water sample to a leaching solution containing a chelating agent or acid that selectively binds to the heavy metals. The solution is then analysed for the presence and concentration of the targeted heavy metal. Separately, three 5L PVC containers were used to place blocks with 5%, 10%, and 15% partial replacement. Leached materials were then tested by exposing water to them for 24 hours, 48 hours, and 72 hours consecutively, totalling 3 days. Notable parameters for heavy metal testing included Chromium (Cr), as well as aluminium, ferrous, and silicon. In Figure 3(b), the heavy metal concentration rate was determined using the HACH DR 6000™ UV-VIS spectrometer, following the manual provided by the HACH company.

(a) **(b)**

Figure 3: (a) Leaching water container with a blind cap at the bottom, (b) Hach spectrometer for calculating the heavy metal concentration

3. RESULTS AND DISCUSSIONS

3.1 Compressive strength analysis

The properties of fine aggregate, coarse aggregate, cement, and paint sludge are outlined in table 1. The accepted test method (ASTM) were employed to get the results of properties of concrete materials, as presented in the following sequence.

Table 1: Properties of Materials used in this study for concrete casting

	Parameters of the materials			
Properties	**Fine aggregate**	**Coarse aggregate**	**Cement**	**Paint sludge**
Fineness modulus	-	-	1.66	-
Specific gravity	2.62	2.72	3.13	2.02
Unit weight (Kg/m³)	1497.29	1613.75	-	-
Absorption capacity (%)	1.98	0.67	-	-
Moisture content (%)	2	0.71	-	-
Consistency (%)	-	-	28	-
Initial setting time	-	-	30 min	-
Final setting time	-	-	6 hours 20 min	-

In figure 4, the results of 36 cube blocks tested with 5%, 10%, and 20% proportions of paint sludge as a partial replacement for cement have been recorded. A comprehensive analysis of the suitability of paint sludge as a partial replacement has been conducted. Additionally, an examination of the sustainability implications of using paint sludge as a partial replacement and its impact on the environment, along with an assessment of its eco-friendly behavior in various contexts, has been performed in this study.

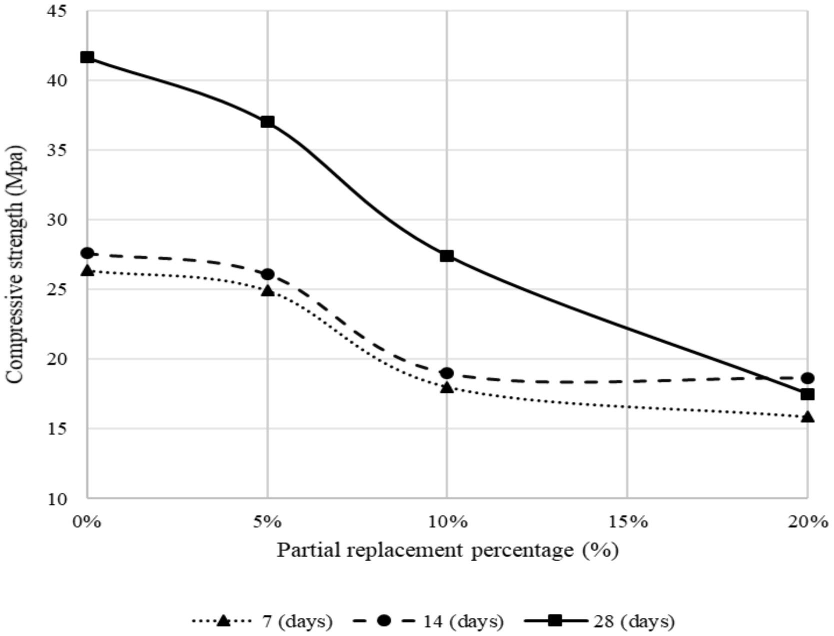

Figure 4: Influence of partial cement Replacement by paint sludge on compressive strength on concrete.

Compressive strength analysis was conducted for 9 blocks with 0% partial replacement and, correspondingly, for 36 blocks with 5%, 10%, and 15% replacements. It is observed that for 0% replacement, the compressive strength values at 7 days, 14 days, and 28 days were 26.37, 27.59, and 41.3 MPa, respectively as shown in Figure 4. In this case, as the amount of partial replacement increased, the compressive strength gradually decreased. In Figure 4, for 5% and 10% partial replacements, the compressive strength values across three curing periods were as follows: 24.49 Mpa, 26.10 Mpa, 37.00 Mpa, 18.01 Mpa, 19.00 Mpa, and 27.43 Mpa, respectively. Despite gaining strength with an increase in the curing period, the use of partial replacement led to a reduction in the strength values. At 20% replacement, there was a decline in compressive strength, falling within the range of 20-15 Mpa, which is lower than the compressive strength of no partial replacement at 7 days (see Figure 4). However, with a 5% partial replacement, the compressive strength value at 28 days approached that of no replacement, as shown in Figure 4.

3.2 Presence and consequence of metallic concentration

The use of paint sludge as a partial replacement in testing or study was another crucial aspect. It needs to be investigated whether it will have a detrimental impact on the environment and if there are any environmentally advantageous conditions. In this context, the heavy metal concentration rates in leaching water after 7 days were the highest (see figure 5). The primary reason for this was the lack of proper strength gain during the initial 7 days, leading to higher leaching amounts, with the most significant concentration rates of chromium (Cr) observed at 20% replacement on test days 1, 2, 3, (24, 48, and 72 hours), being 0.081, 0.089, and 0.092 mg/L as shown in figure 7, respectively. Chromium concentration ranged from 0.009 to 0.092 mg/L, staying within the specified limit, while ferrous concentration varied from 0.0 to 0.4 mg/L, also within the permissible range.

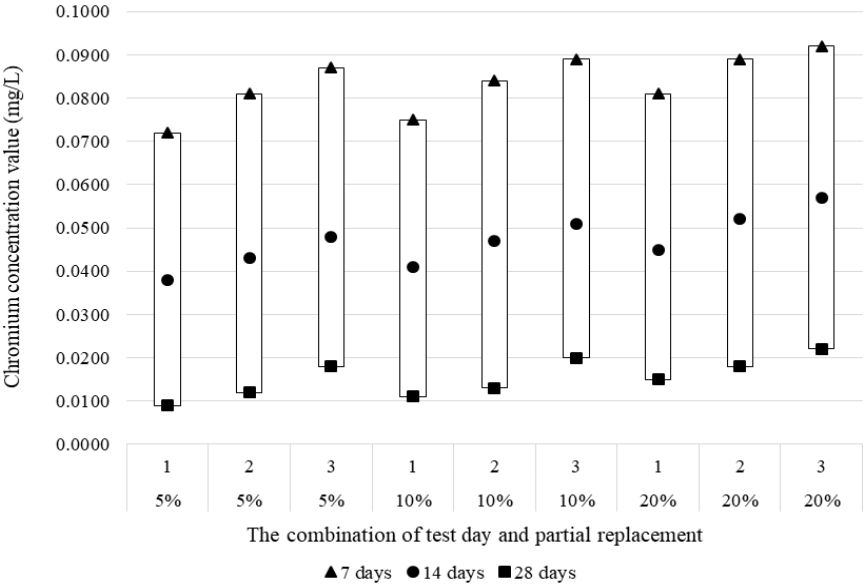

Figure 5: Chromium Concentration Rate Values in Partial Replacement and Test Day Variations

The chromium concentration rate increased from approximately 0.0100 mg/L to 0.0200 mg/L within a curing period of 28 days. Similarly, during a 14-day curing period, the concentration ranged from 0.0400 mg/L to 0.0600 mg/L. After an additional 7 days of curing, the chromium concentration was constrained between 0.0700 mg/L and 0.0900 mg/L in Figure 5. This escalation in concentration is attributed to the prolonged curing period, leading to increased strength and reduced leaching. Our primary objective was to ascertain the migration of heavy metals, particularly chromium, and comprehend its environmental impact. Furthermore, upon analyzing the silicon concentration, it was observed that at 5% partial replacement on test day 3 (72 hours), the maximum concentration rate was found to be 75.7 mg/L as shown in Figure 8, within the specified limit ranging from 75.7 to 10.7 mg/L. An additional crucial element in paint sludge is silicon, which plays a significant role in coatings, acting as an additive and contributing to chemical resistance.

In the case of silicon concentration, it is observed that the rate of presence of silicon is highest at test day 3 or 72 hours as shown in Figure 6. On test day 3, for 5%, 10%, and 20% partial replacement with a 7-day curing period, the silicon concentration rates are approximately 75 mg/L, 62 mg/L, and 35 mg/L, respectively as shown in Figure 8. As time progresses, both the leaching quantity and concentration levels increase. Notably, each level of partial replacement exhibits a distinct impact on concentration growth after leaching.

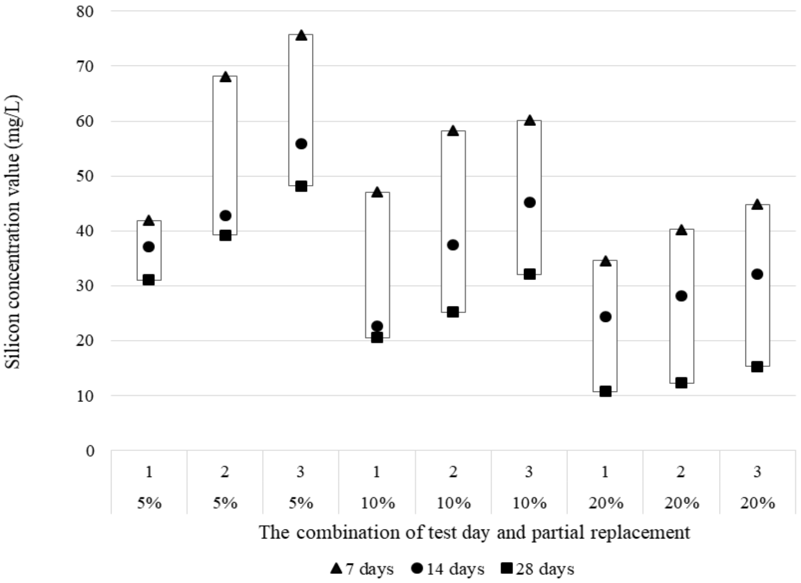

Figure 6: Silicon Concentration Rate Values in Partial Replacement and Test Day Variations

In this case, the pH value ranged from 6.85 to 9.6, remaining within the permissible limits. Therefore, based on the obtained results, it can be concluded that the composite compound of paint sludge contains a minimal amount of heavy metals or harmful substances unbound to the environment, making it environmentally sustainable and eco-friendly.

4. CONCLUSIONS

This research outlines the practical application of paint sludge as a viable partial substitute for cement in concrete blocks, advocating for a recommended replacement cap of 5%. Despite a marginal decline in compressive strength compared to the control sample, the substantial environmental gains, such as addressing paint sludge disposal issues and reducing dependence on carbon-intensive cement production, underscore the significance of this eco-friendly approach. The observed reduction in compressive strength with increased replacement is attributed to insufficient strength gain during the initial curing period, supported by data indicating compressive strength values of 26.37 MPa at 7 days, 27.59 MPa at 14 days, and 41.3 MPa at 28 days for 0% replacement. Leaching tests confirm that heavy metal concentrations consistently fall within regulatory limits, ensuring the safety of the constructed environment. The leaching study affirms the material's minimal environmental impact, with chromium concentrations ranging from 0.009 to 0.092 mg/L, well within acceptable limits, while silicon concentration rates for 5%, 10%, and 20% replacements after a 7-day curing period were approximately 75 mg/L, 62 mg/L, and 35 mg/L, respectively. Overall, our study offers valuable insights into the potential of paint sludge as an environmentally sustainable and economically viable resource in the construction industry. For instance, chromium concentrations remained well below the specified limit, even at a 20% replacement rate, emphasizing the safety profile of the material. This study not only highlights the feasibility of incorporating paint sludge in concrete blocks as a sustainable solution but also puts forward valuable waste management insights and advances in environmentally conscious construction methods. In future investigations, delving into the pozzolanic properties of paint sludge through detailed XRF/XRD analysis is essential, along with exploring its sulphate resistance properties. Additionally, considering the potential utilization of paint sludge in pavement construction is promising for both environmental sustainability and economic viability

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