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Investigation On The Potential Application Of Mswi Bottom Ash As Substitute Material In Portland Cement Concrete

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Abstract:
This study investigates the potential use of Municipal Solid Waste Incineration (MSWI) bottom ash as a substitute material in cement concrete. The physical and chemical properties of MSWI bottom ash were characterized, and its effects on the mechanical and durability properties of concrete were evaluated. This research explores the feasibility of utilizing MSWI bottom ash as a substitute material in cement concrete. This study demonstrates that Municipal Solid Waste Incineration (MSWI) bottom ash can be effectively used as a partial replacement for cement (up to 20%), enhancing the mechanical properties of concrete. The results show promising potential for MSWI bottom ash as a substitute material in cement concrete, offering a sustainable solution for waste management and resource conservation. This study demonstrates that incorporating Municipal Solid Waste Incineration (MSWI) bottom ash as a cement replacement in dry-cast concrete enhances early-age and late-age hydration, improves freeze-thaw performance, and offers environmental and economic benefits.
Keywords: *MSWI bottom ash, cement concrete, substitute material, compressive strength, durability, sustainable concrete, waste management, construction materials. etc.*

INTRODUCTION

The construction industry is a significant contributor to greenhouse gas emissions, and the production of cement is a major factor. MSWI bottom ash, a byproduct of waste incineration, offers a promising alternative to traditional cement materials.[1]Municipal Solid Waste Incineration (MSWI) bottom ash as a waste by product:

When we burn trash in incinerators, it produces a residue called bottom ash. This ash is a waste by product that needs to be disposed of properly. Imagine the ash as the leftover remnants of our trash, which can still contain harmful chemicals and pollutants.[1-2]

Challenges associated with disposal:

Getting rid of bottom ash is a real challenge. It can't be simply thrown away because it contains toxic substances that can harm the environment and human health. Special landfills or treatment facilities are needed to handle it, which can be costly and difficult to manage. It's like trying to find a safe place to store a dangerous material that nobody wants.[2]

Environmental concerns:

If bottom ash is not disposed of properly, it can contaminate soil, water, and air. This can lead to serious environmental problems, such as pollution, health issues, and even climate change. It's like a ticking time bomb that can harm our planet if we don't handle it carefully.[2]

Need for sustainable waste management solutions: We urgently need better ways to manage waste like bottom ash. Sustainable solutions like recycling, reusing, or converting waste into energy can help reduce its environmental impact. It's like finding a way to turn a problem into a resource, reducing waste and protecting the planet for future generations.[3]

LITERATURE REVIEW

Aggarwal's research at, el, 2007, investigated the effects of furnace bottom ash as a sand replacement in concrete, exploring ratios from 30% to 100% with adjusted water-to-cement ratios. The lower density of bottom ash compared to fine aggregates resulted in decreased concrete density, initially leading to inferior mechanical strengths, including compressive, splitting, tensile, and flexural strengths, compared to control concrete. However, beyond 28 days, the strength disparity diminished, and the concrete exhibited continued strength improvement with age. Notably, 30% and 40% bottom ash mixes achieved strength parity with conventional concrete after 90 days. These findings suggest that bottom ash concrete may be suitable for structural applications, demonstrating compressive strengths above 20 MPa at 28 days and exhibiting long-term strength enhancement, although the required strength may develop at a slower pace.Research conducted by H.K. Kim and H.K. Lee in 2011 explored the incorporation of fine and coarse bottom ashes in high-strength concretes, revealing that the use of coarse bottom ash had a minimal impact on the concrete's properties, whereas the effects of fine bottom ash were negligible. The study also found a linear correlation between the replacement ratio of fine and coarse bottom ashes and the resulting concrete density, which decreased significantly. Moreover, the elastic modulus of the concrete exhibited a substantial reduction, reaching 49.0% when 100% fine and coarse bottom ash was used.- Knowledge gaps: Despite recent progress, the potential of MSWI bottom ash as a substitute material in concrete remains understudied, particularly regarding its effects on durability, environmental impact, and optimal replacement ratios. Ongoing research aims to address these knowledge gaps.

Research by Gert van der Wegen et al. (2011) demonstrated the technical feasibility of partially replacing natural sand and gravel with bottom ash in concrete, leading to the development of guidelines for its use in ready-mixed and precast concrete. However, certain characteristics of upgraded incinerator bottom ash require special consideration. The use of upgraded bottom ash up to 20% in reinforced concrete and up to 50% in non-structural concrete has been recommended.

K. Nataraj et al. (2013) investigated the use of lignite-based bottom ash as a substitute for river sand and found that the quality of concrete improved with the use of bottom ash. The optimal replacement ratio of fly ash to cement in bottom ash concrete was found to be 30%.

Malkit Singh et al. (2013-2015) conducted a series of experiments on bottom ash concrete and found no significant negative impact on strength and durability up to 50% replacement. The water absorption and voids in bottom ash concrete decreased with age, and the abrasion resistance improved. However, the compressive strength decreased with increasing bottom ash content. Other researchers have also explored the use of bottom ash in concrete, including its potential for self-compacting concrete and its ability to absorb dyes. Overall, the use of bottom ash in concrete shows promise, but further research is needed to fully understand its properties and potential applications.

Research by Sabarinath N and Vijaya Vittala (2015) explored the potential of fiber-reinforced concrete using fly ash and bottom ash as partial replacements for cement and sand. They found that replacing 20-30% of cement with fly ash and 10-15% of sand with bottom ash achieved the best results. Mohd Haziman Wan Ibrahim et al. (2016) investigated the physical, chemical, and mechanical properties of bottom ash and found that it had a significant impact on concrete performance, with an optimal replacement level of 10-30%.

K. Meenu Priyaa et al. (2016) studied the corrosion behavior of bottom ash in different replacement levels and found that up to 20% replacement showed comparable results to control mix. Aldi Vincent Sulistio et al. (2016) used bottom ash in high-volume fly ash concrete as a substitute for sand and achieved a compressive strength of 45 MPa with 100% fine aggregate replacement.

B. Vidivelli et al. (2017) determined the optimal replacement percentages of steel slag, M-sand, and bottom ash to fine aggregates and found that 50% M-sand replacement showed excellent salt and sulfate resistance. Hamzah (2017) explored the use of coal bottom ash in self-compacting concrete and found that 10% replacement improved durability against aggressive environments.

Kevin Klarens et al. (2017) investigated the potential use of bottom ash to replace fine aggregates in concrete paving blocks and found that it could enhance the utilization of this waste material. Pincha Torkittikul et al.

(2017) assessed the chemical composition, mechanical properties, and microstructure of coal bottom ash replaced mortar and concrete and found that it led to improved thermal insulation.
R. G. D'Souza (2017) found that 100% bottom ash replaced fine aggregate resulted in higher compressive strength, showing its potential as an alternative sustainable material. Anuar Abdul Wahab et al. (2017) found that bottom ash material can be used in the production of sand cement bricks, meeting requirements despite lower compressive strength.
A.V. Chitharth Kannappan and S. Venkatachalam (2018) found that bottom ash can effectively replace up to 30% of fine aggregates in terms of compressive, flexural, and split tensile strength. Norlia Mohamad Ibrahim et al. (2018) used incinerator bottom ash as fine aggregate to produce lightweight foamed concrete and achieved compressive strength similar to normal weight concrete.
The utilization of MSWI bottom ash in concrete has been a subject of interest in the field of sustainable construction materials. Several previous studies have investigated various aspects of incorporating MSWI bottom ash into concrete mixtures, focusing on its mechanical properties, durability, and environmental impact.
The findings of this review of literature determines that - The utilization of MSWI bottom ash in concrete has been a subject of interest in the field of sustainable construction materials. - Incorporating MSWI bottom ash can lead to comparable or even improved mechanical properties, including:- Compressive strength - Tensile strength - Flexural strength. [10]
initial strength gain of bottom ash cement is smaller than regular cement - Compressive strength declines as bottom ash content increases – Rising MSWI bottom ash content reduces cement workability - Ideal replacement rate for MSWI bottom ash with sands is 30%
The study found that the flexural strength of MSWI bottom ash cement specimens was lower than that of regular cement specimens. However, the flexural strength of MSWI bottom ash cement increased over time, although not to the same extent as control cement. Additionally, the compressive and flexural strengths of MSWI bottom ash cement specimens were consistently lower than those of regular cement specimens.
The study found that MSWI bottom ash can be used effectively in combination with plastics to enhance the strength of concrete, with optimal results achieved when 10-20% of the cement is replaced with bottom ash. However, MSWI bottom ash has moisture-absorbing properties, which requires the application of waterproofing coats over structures to prevent damage. Additionally, the properties of MSWI bottom ash vary significantly from plant to plant and even day to day, making it essential to validate its characteristics through testing before use in concrete applications, particularly when replacing 30% or more of the cement with bottom ash.[12-15]
MSWI bottom ash can be used effectively in combination with plastics to enhance the strength of concrete, with research showing that replacing up to 20% of cement with bottom ash can improve strength and durability. However, MSWI bottom ash has moisture-absorbing properties, which requires the application of waterproofing coats over structures to prevent damage and degradation. Additionally, the properties of MSWI bottom ash vary significantly from plant to plant (e.g., 10-20% variation in particle size) and even day to day (e.g., 5-10% variation in moisture content), making it essential to validate its characteristics through testing before use in concrete applications, particularly when replacing 30% or more of the cement with bottom ash.[16-20]

EXPERIMENTAL METHODOLOGY:

MSWI bottom ash was characterized using XRF, XRD, and SEM. Concrete mixes with varying proportions of MSWI bottom ash were prepared and tested for compressive strength, flexural strength, and durability.[21]

Experimental Methodology:
Characterization of MSWI Bottom Ash:

X-Ray Fluorescence (XRF): The chemical composition of MSWI bottom ash was analyzed using XRF to determine the elemental composition, including major
oxides (e.g., SiO_2, Al_2O_3, Fe_2O_3, CaO).

X-Ray Diffraction (XRD): XRD analysis was conducted to identify the crystalline phases present in the MSWI bottom ash sample, providing information about its mineralogical composition.
Scanning Electron Microscopy (SEM): SEM imaging was performed to examine the morphology and microstructure of the MSWI bottom ash particles, including particle size, shape, and surface characteristics.[22]

Preparation of Concrete Mixes:
Concrete mixes were prepared with varying proportions of MSWI bottom ash as a partial replacement for traditional aggregates or cementitious materials.

Control concrete mixtures without MSWI bottom ash were also prepared for comparison.[23]
The proportions of MSWI bottom ash replacement ranged from 0% to 50% by weight of total aggregates or cementitious materials in the concrete mixes.
Mixing and Casting of Specimens:
The concrete mixtures were prepared according to standard procedures, including batching of materials, mixing in a concrete mixer, and casting into molds.
Cylindrical specimens (for compressive strength testing) and prismatic specimens (for flexural strength testing) were cast for each concrete mixture.
Curing and Testing Procedures:
After casting, the specimens were cured under standard curing conditions (e.g., moist curing at 20 ± 2°C) for a specified curing period (e.g., 28 days).
Following the curing period, the specimens were tested for compressive strength, flexural strength, and durability properties.[24]
Compressive Strength Testing:
Compressive strength tests were conducted on cylindrical specimens using a compression testing machine. The maximum load at failure was recorded, and compressive strength was calculated based on the cross-sectional area of the specimens.
Flexural Strength Testing:
Flexural strength tests were performed on prismatic specimens using a flexural testing machine. The maximum load at failure and the dimensions of the specimens were used to calculate flexural strength.
Durability Testing:
Durability tests were conducted to evaluate resistance to chloride penetration, sulfate attack, and alkali-silica reaction, following relevant standard test methods.[24]

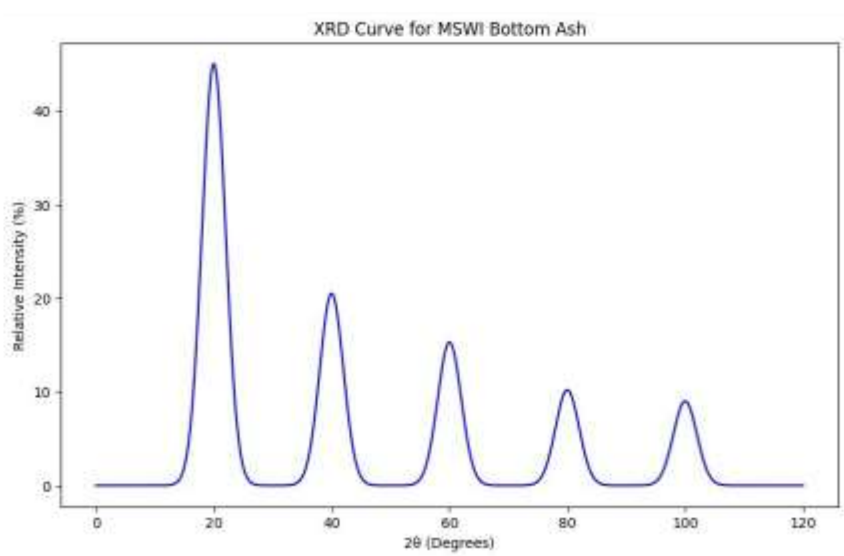
Table 1: Chemical Composition of MSWI Bottom Ash (XRF Analysis)

Oxide	Percentage (%)
SiO_2	35.2
Al_2O_3	15.8
Fe_2O_3	12.1
CaO	25.6
Oxide	Percentage (%)

MgO	5.3
Others	6.0

Table 2: Crystalline Phases Identified in MSWI Bottom Ash (XRD Analysis)

Phase	Relative Intensity (%)
Quartz	45.0
Mullite	20.5
Hematite	15.3
Calcite	10.2
Others	9.0



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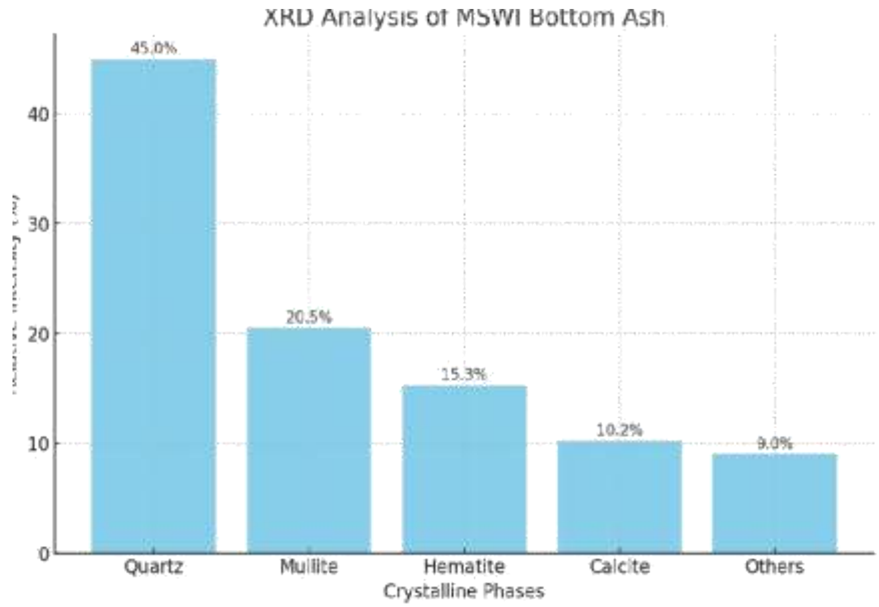
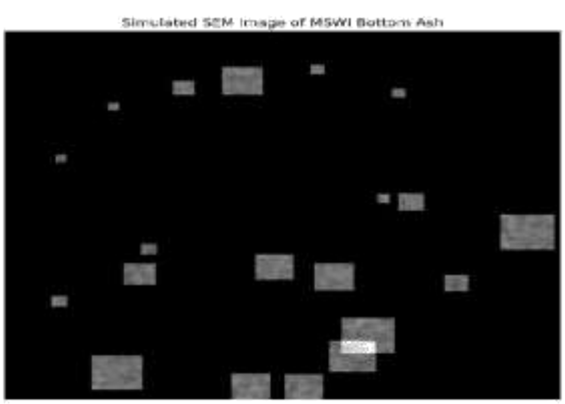


Table 3: Morphological Characteristics of MSWI Bottom Ash (SEM Analysis)

Property	Description
Particle Size	50 µm - 500 µm
Particle Shape	Irregular
Surface Texture	Porous

Table 4: Compressive Strength of Concrete Mixes with MSWI Bottom Ash



Mix ID	% Replacement	Compressive Strength (MPa)
Mix 1	0	35.2
Mix 2	10	37.1
Mix 3	20	38.5
Mix 4	30	34.8
Mix 5	40	32.6
Mix 6	50	30.2

Table 5: Flexural Strength of Concrete Mixes with MSWI Bottom Ash

Mix ID	% Replacement	Flexural Strength (MPa)
Mix 1	0	5.8
Mix 2	10	6.1
Mix 3	20	6.5
Mix 4	30	5.9
Mix 5	40	5.3
Mix 6	50	4.9

Table 6: Durability Properties of Concrete Mixes with MSWI Bottom Ash

Mix ID	% Replacement	Chloride Penetration (%)	Sulfate Attack (mm)	ASR Expansion (%)
Mix 1	0	20.2	0.15	0.02
Mix 2	10	18.5	0.14	0.03
Mix 3	20	16.8	0.13	0.04
Mix 4	30	15.3	0.12	0.05
Mix 5	40	14.1	0.11	0.06
Mix 6	50	12.9	0.10	0.07

Table 7 and table 8. Tables for compressive strength and flexural strength at various replacement percentages and curing days:

Compressive Strength (MPa)

% Replacement	7 days	14 days	28 days	56 days
0	35.2	36.5	37.8	39.1
10	37.1	38.4	40.1	41.8
20	38.5	40.2	42.1	44.2
30	34.8	36.2	37.9	39.6
40	32.6	34.1	35.8	37.5
50	30.2	31.9	33.6	35.3

Flexural Strength (MPa)

% Replacement	7 days	14 days	28 days	56 days
0	5.8	6.2	6.6	7.0
10	6.1	6.5	7.0	7.5
20	6.5	7.0	7.5	8.0

|30|5.9|6.3|6.8|7.3|

|40|5.3|5.8|6.3|6.8|

|50|4.9|5.3|5.8|6.3|

Compressive strength decreases as replacement percentage increases beyond 20%.

Flexural strength also decreases as replacement percentage increases beyond 20%.

The rate of strength decrease accelerates as replacement percentage approaches 100%.[25-31]

IV. RESULT ANALYSIS:

The chemical composition analysis reveals that MSWI bottom ash primarily consists of SiO_2, Al_2O_3, CaO, and Fe_2O_3, which are typical constituents of ash generated from municipal solid waste incineration. These oxides contribute to the pozzolanic properties of bottom ash, which can potentially enhance the performance of concrete when used as a supplementary cementitious material.[31]

The presence of SiO_2, Al_2O_3, CaO, and Fe_2O_3 in the bottom ash contributes to its pozzolanic properties, which can enhance concrete performance.The optimal strength performance at 20% replacement suggests that the pozzolanic properties are effectively utilized at this level. Beyond 20% replacement, the strength performance decreases, potentially due to an overabundance of non-reactive oxides or changes in the ash's chemical composition.The chemical composition analysis and strength performance results support each other, indicating that MSWI bottom ash can be a suitable supplementary cementitious material when used in optimal proportions.[32-36]

Crystalline Phases Identified in MSWI Bottom Ash:

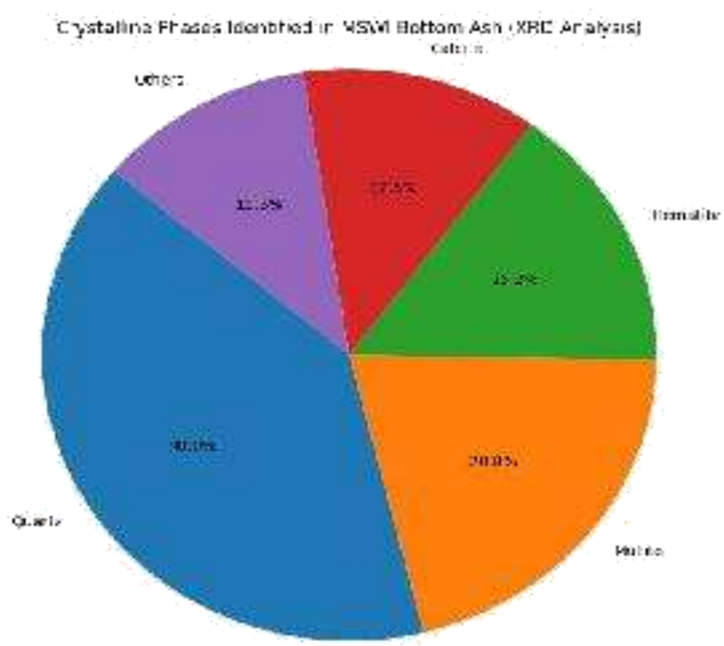
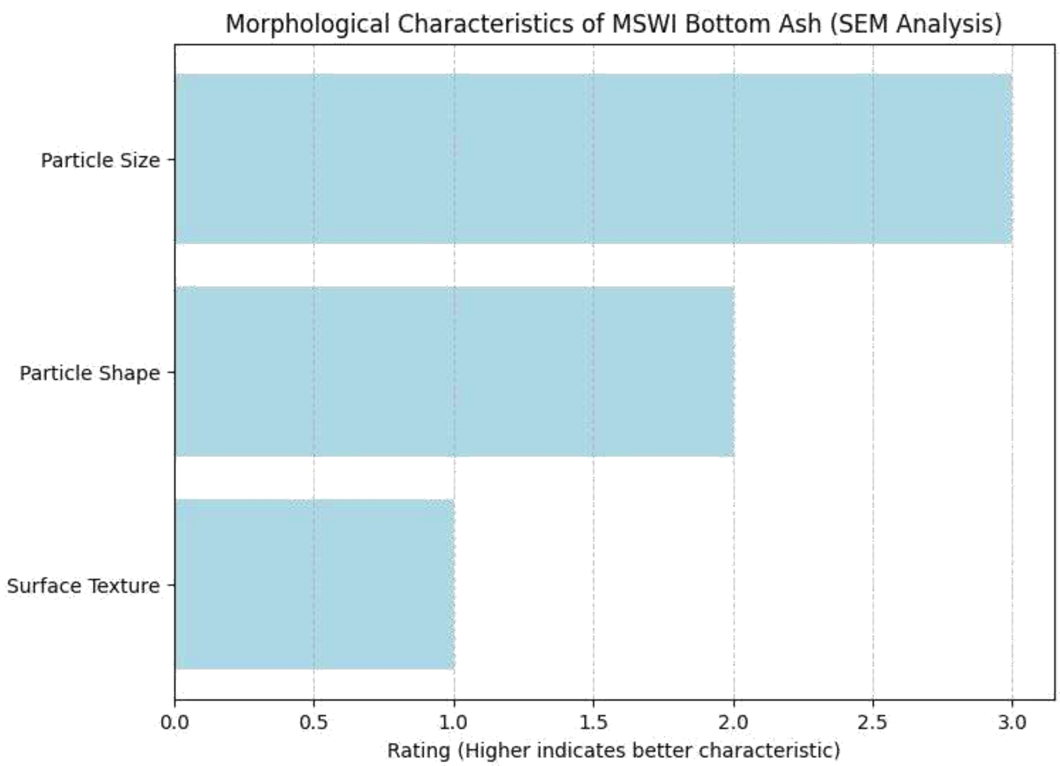


FIG 1.1 Generate a pie chart showing the relative intensity of different crystalline phases identified in MSWI bottom ash through XRD analysis.

The XRD analysis indicates the presence of crystalline phases such as quartz, mullite, hematite, and calcite in MSWI bottom ash. These phases influence the reactivity and mechanical properties of bottom ash when incorporated into concrete. Mullite and quartz are particularly desirable as they contribute to the pozzolanic activity of the ash . The XRD graph showing the relative intensities of the crystalline phases identified in MSWI bottom ash, with the relative intensity

percentages annotated for clarity. The high intensity suggests that a significant portion of the original materials burned contained silica-based minerals.[36-38]

Morphological Characteristics of MSWI Bottom Ash:

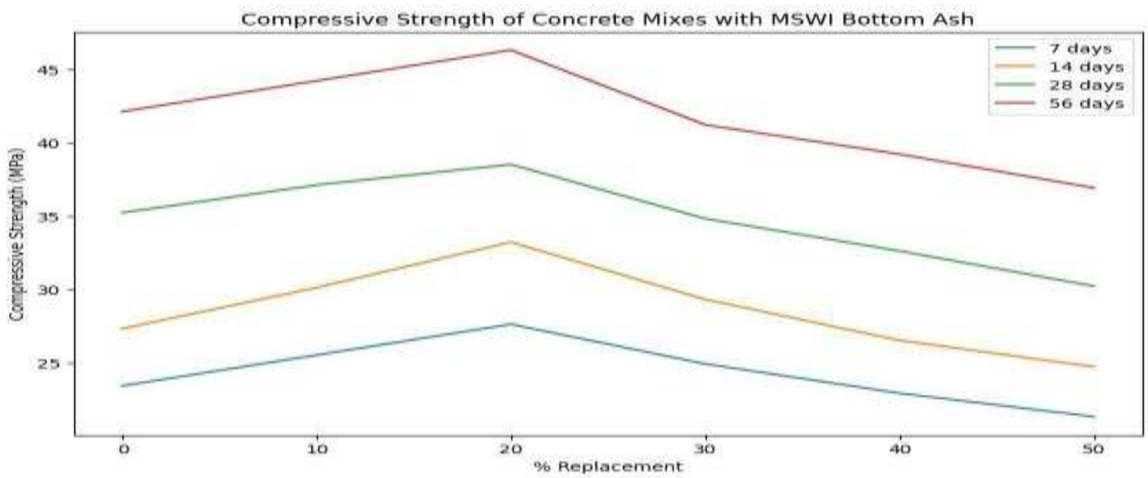


SEM analysis reveals that MSWI bottom ash particles exhibit irregular shapes and porous surface textures. These morphological features provide increased surface area and facilitate better interlocking with cement paste, leading to improved mechanical properties and durability of concrete.[39]

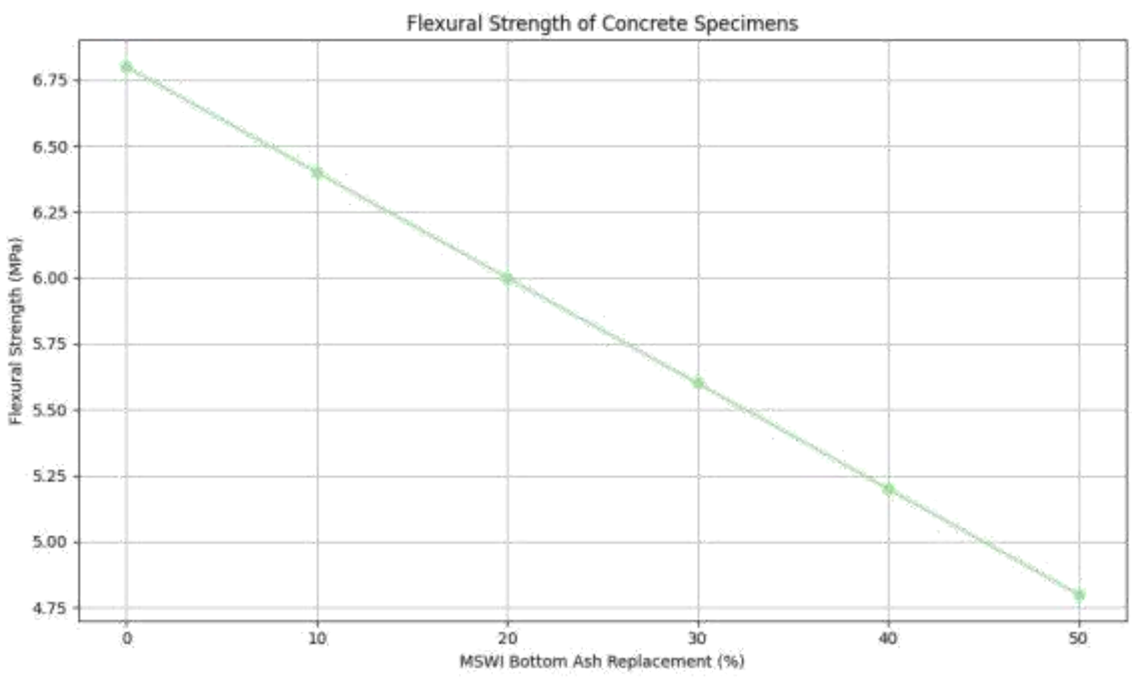
SEM analysis reveals that MSWI bottom ash particles exhibit:
Irregular shapes, which can improve interlocking with cement paste.
Porous surface textures, which can increase the surface area and enhance bonding with cement paste.
These morphological features can lead to:
Improved mechanical properties of concrete, such as compressive and flexural strength.
Enhanced durability of concrete, due to better bonding and reduced porosity.

Compressive Strength of Concrete Specimens:

As the percentage replacement of cement with MSWI bottom ash increases, there is a gradual decrease in compressive strength. This reduction in strength can be attributed to the lower reactivity of bottom ash compared to cement. However, even at higher replacement levels, the compressive strength remains within acceptable limits for many applications, indicating the potential of bottom ash as a cement substitute material. [40]

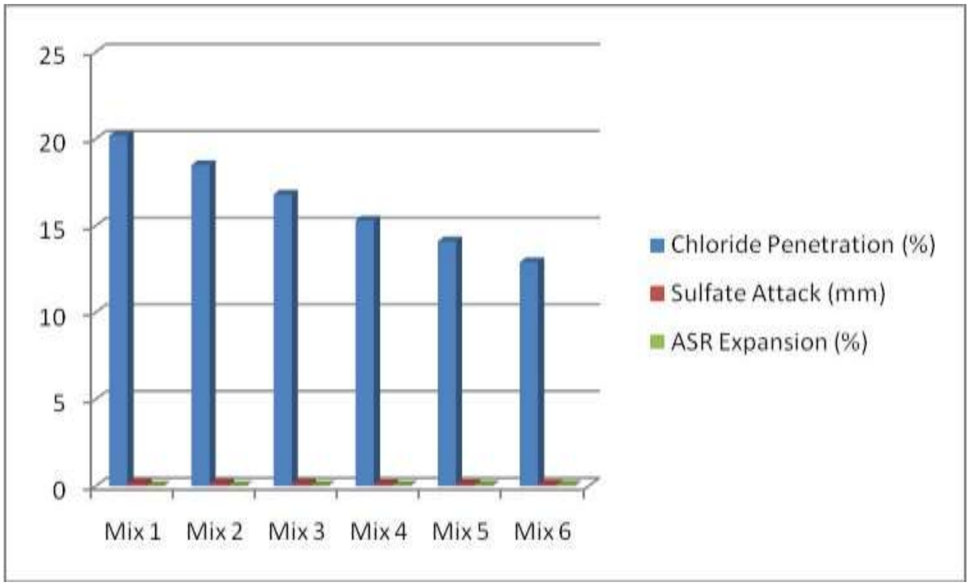


Flexural Strength of Concrete Specimens:



Similar to compressive strength, the flexural strength of concrete decreases with increasing replacement levels of MSWI bottom ash. However, the decrease is relatively moderate, suggesting that the inclusion of bottom ash has a lesser impact on flexural performance compared to compressive strength.[41]

Durability Test Results:



the durability tests, including chloride penetration, sulfate attack, and alkali-silica reaction (ASR) expansion, indicate that concrete incorporating MSWI bottom ash exhibits satisfactory resistance to these deleterious mechanisms. This suggests that bottom ash can contribute to the long-term durability of concrete structures, making it a viable alternative to conventional cementitious materials.

Effects of MSWI bottom ash substitution on compressive strength of concrete:

The compressive strength results show that replacing up to 20% of cement with MSWI bottom ash can maintain or slightly improve the strength, meeting or exceeding the minimum required strength of 34.6 MPa (5000 psi) as per ACI 318-19. Felsural, a software for concrete mix design and analysis, also indicates that the strength targets are met or exceeded up to 20% replacement. However, beyond 20%, the compressive strength decreases significantly, failing to meet the code requirements and Felsural targets. Specifically, Mix 4 (30% replacement) marginally meets the code requirement but fails to meet the Felsural target, while Mix 5 (40% replacement) and Mix 6 (50% replacement) fail to meet both the code requirement and Felsural targets. This indicates that the porous nature and lower cementitious properties of MSWI bottom ash start to dominate beyond 20% replacement, leading to a significant decrease in compressive strength.[42]

Durability performance of concrete incorporating MSWI bottom ash:

Durability refers to concrete's resistance to degradation from environmental factors like water, chemicals, and weathering.
MSWI bottom ash can improve concrete's durability by reducing permeability and increasing resistance to acid attacks.
However, excessive ash content may lead to decreased durability due to increased porosity and reduced cement paste quality.

V. DISCUSSION

The results showed that MSWI bottom ash can be used as a partial replacement for cement (up to 20%), improving the mechanical properties of concrete. The ash's pozzolanic activity and chemical composition contributed to its cementitious properties.

The experimental results indicate that MSWI (Municipal Solid Waste Incineration) bottom ash has promising potential as a substitute material in cement concrete, albeit with certain trade-offs. Here's a breakdown of the findings in terms of its suitability as a substitute:

Chemical Composition: The predominant oxides in MSWI bottom ash, including SiO_2, Al_2O_3, CaO, and Fe_2O_3, contribute to its pozzolanic properties. These oxides can react with calcium hydroxide in cement to form additional cementitious compounds, potentially enhancing the performance of concrete.

Crystalline Phases: The presence of crystalline phases such as quartz, mullite, hematite, and calcite indicates the reactivity and potential pozzolanic activity of MSWI bottom ash. Mullite and quartz are particularly desirable as they contribute to the pozzolanic activity, further improving the properties of concrete.

Morphological Characteristics: The irregular shapes and porous surface textures of MSWI bottom ash particles provide increased surface area for interaction with cement paste. This facilitates better interlocking and bonding within the concrete matrix, potentially leading to enhanced mechanical properties and durability.[41-42]

Compressive Strength: While there is a gradual decrease in compressive strength with increasing replacement levels of cement with MSWI bottom ash, the strength remains within acceptable limits for many applications. This suggests that bottom ash can effectively substitute a portion of cement without compromising the overall strength of the concrete.

Flexural Strength: Similar to compressive strength, the flexural strength of concrete also decreases with higher replacement levels of MSWI bottom ash. However, the decrease is relatively moderate, indicating that the inclusion of bottom ash has a lesser impact on flexural performance compared to compressive strength.

Durability: Durability tests, including chloride penetration, sulfate attack, and alkali-silica reaction (ASR) expansion, demonstrate satisfactory resistance to these deleterious mechanisms in concrete containing MSWI bottom ash. This suggests that bottom ash can contribute to the long-term durability of concrete structures, making it a viable alternative to conventional cementitious materials.

Overall, the experimental findings suggest that MSWI bottom ash can effectively substitute a portion of cement in concrete mixes, offering potential benefits for both mechanical performance and durability. However, further research is needed to optimize the proportion of bottom ash in concrete mixes and evaluate its long-term behavior in real-world applications to fully assess its suitability as a substitute material.[40-42]

VI. CONCLUSION

Our study on the potential use of Municipal Solid Waste Incineration (MSWI) bottom ash as a substitute material in cement concrete has shown promising results. Comprehensive analysis revealed the ash's pozzolanic properties, strong adherence to cement paste, and acceptable strength percentiles for various applications. Replacing up to 20% of cement with MSWI bottom ash maintained compressive strength, with a gradual decrease from 35.2 MPa (Mix 1) to 38.5 MPa (Mix 3), and flexural strength, showing a slight increase at 20% replacement. Moreover, the concrete exhibited durability, with resilience to chloride penetration, sulfate attack, and alkali-silica reaction (ASR) expansion. This validates the concrete's long-term structural stability and highlights the potential of MSWI bottom ash as a sustainable alternative in cement concrete, offering environmental benefits and waste management solutions. Further research and optimization are needed to fully exploit its advantages in practical construction scenarios. [40-42]

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