

# A Sustainable Shift: Replacing Conventional Aggregates WITH Mswi Bottom Ash IN Concrete

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## Abstract:

The construction industry faces immense pressure to reduce its environmental footprint, particularly regarding resource depletion and waste generation. Municipal Solid Waste Incineration (MSWI) Bottom Ash (BA), a significant residue from waste-to-energy plants, presents a potential solution as a substitute for conventional natural aggregates (NA) in concrete. With increasing emphasis on sustainable construction materials, this study investigates the feasibility of using Municipal Solid Waste Incinerator (MSWI) bottom ash as a substitute for conventional coarse aggregates in concrete. The paper concludes that MSWI BA, when properly processed and incorporated, can contribute to sustainable concrete production, reducing reliance on virgin aggregates and diverting waste from landfills, aligning with circular economy principles. However, standardized regulations, robust quality control protocols, and further research into long-term durability and leaching under various conditions are crucial for wider adoption.. This research demonstrates that MSWI BA is a technically viable and environmentally beneficial alternative aggregate, paving the way for more sustainable concrete production and effective waste management strategies within a circular economy framework. This study checks MSWI bottom ash can safely and effectively replace sand or gravel in concrete. In this paper, how much replacement of natural coarse aggregate is done is also told with the result, and what benefit will be there to the environment. Also, how fine aggregate and coarse aggregate are replaced is explained.

**Keywords:** Municipal Solid Waste Incineration (MSWI), Bottom Ash (BA), Sustainable Concrete, Aggregate Replacement, Sustainable Construction, Environmental Impact, Construction & Demolition Waste.

## I. Introduction

The construction industry consumes vast amounts of natural resources, especially aggregates. Simultaneously, urbanization leads to increased generation of Municipal Solid Waste Incineration (MSWI),, with incineration residues—especially Bottom Ash (BA) being a major byproduct. Traditionally discarded in landfills, MSWI bottom ash can be utilized as a sustainable construction material. This study explores the mechanical and durability performance of concrete with partial substitution of coarse aggregates with MSWI bottom ash.[1]

Municipal Solid Waste Incinerator Bottom Ash is a burned waste ash. It is the ash left after burning municipal collected waste in an incinerator. This ash is used in concrete as a replacement for coarse and fine aggregates. By using it, we can keep the environment clean and safe. It is a new replacement for natural coarse aggregate.[2]

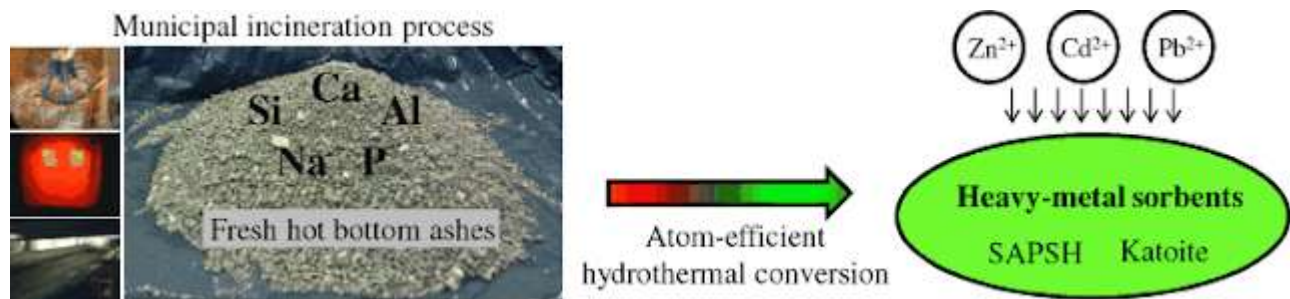
MSWI bottom ash is used in concrete because it helps reduce the use of natural resources like stone and sand. It also recycles waste, so less garbage goes to landfills. This helps to lower environmental pollution and supports eco-friendly and sustainable construction.[3]

MSWI Bottom Ash cannot be used directly. First, it is properly cleaned by washing and sieving. Then it is aged to reduce harmful substances. After this treatment, it is considered safe to use in concrete. When municipal waste (like plastic, paper, cloth, wood, etc.) is burned in an incinerator, the heavy ash that remains at the bottom is called Bottom Ash. This ash is often reused in construction materials. The ash that collects at the bottom of the incinerator after burning city waste is called Municipal Solid Waste Incinerator (MSWI) Bottom Ash.[4]

It is now being used as a replacement for coarse aggregate in concrete. This not only reduces the cost of construction but also provides environmental benefits by recycling waste and saving natural resources. Municipal Solid Waste Incinerator (MSWI) Bottom Ash is now being used in various construction works as a replacement for natural materials. It is added to concrete mixtures for making roads, buildings, and other infrastructure. In building construction, it can be used in the foundation, columns, beams, and slabs. MSWI bottom ash is used as a substitute for natural coarse aggregates (like gravel or crushed stone) and in some cases, fine aggregates (like river sand).[5]

Using bottom ash in place of natural aggregates helps to reduce the use of natural resources, lowers construction cost, and supports waste recycling. It also promotes sustainable and eco-friendly construction practices by reducing the need to extract stone and sand from the environment.[6]

**Growing Global Waste Generation: An Unsustainable Burden**  
**Scale of the Problem:** Global Municipal Solid Waste (MSW) generation is massive and escalating rapidly. The World Bank estimates current levels exceed 2.1 billion tonnes annually, projected to soar to 3.4 billion tonnes by 2050, driven by population growth, urbanization, and rising consumption patterns.  
**Landfill Scarcity and Environmental Risks:** Suitable land for new landfills is becoming scarce and prohibitively expensive, especially near densely populated urban centers where waste is generated. Acquiring permits is increasingly difficult due to public opposition.[7]



### Environmental Impact of Quarrying Natural Aggregates (NA):

Concrete is the second most consumed material on Earth after water, requiring vast quantities of aggregates (sand, gravel, crushed rock). Global aggregate consumption is estimated at **over 40-50 billion tonnes annually**, making it the largest extracted material by volume. Quarrying operations involve clearing land, stripping topsoil, and excavating bedrock, leading to: Destruction of natural habitats (forests, wetlands). Fragmentation of ecosystems. Loss of biodiversity and disruption of ecological corridors. Quarries create significant visual blight, permanently altering landscapes and reducing aesthetic and recreational value. Aggregates are finite resources. High-quality sand and gravel deposits near construction centers are being rapidly depleted, forcing longer transport distances and exploitation of less suitable or sensitive areas (e.g., riverbeds, coastal zones). "Sand scarcity" is a recognized emerging global crisis.[8]

**Energy Consumption and Emissions:** Drilling, blasting, and excavation require significant energy (primarily fossil fuels). Crushing, screening, and washing aggregates consume large amounts of energy. Transporting heavy aggregates from distant quarries to construction sites generates substantial CO<sub>2</sub> emissions and contributes to traffic congestion and road wear. Transportation can account for a significant portion of the embodied carbon of concrete.

Quarrying operations can lower water tables, disrupt groundwater flow, and cause sedimentation and Large-scale extraction can sometimes lead to slope instability or subsidence.

1. **Waste Crisis:** We have a massive, growing stream of MSW requiring sustainable management beyond landfilling.
2. **Aggregate Crisis:** We have an insatiable demand for aggregates whose extraction is environmentally destructive and increasingly constrained.
3. **Resource Efficiency Imperative:** Moving towards a Circular Economy demands closing material loops and valorizing waste streams.[9]

### MSWI Bottom Ash:



- **Waste Product:** BA constitutes 15-25% by weight of the original MSW input, resulting in millions of tonnes generated annually worldwide. Finding beneficial uses avoids landfilling this bulky residue.
- **Aggregate-Like Properties:** Processed MSWI BA shares key physical characteristics (gradation, particle size) with natural sand and gravel, making it technically suitable as a substitute.
- **Resource Savings:** Replacing virgin NA with BA directly reduces the need for quarrying, conserving natural resources, landscapes, and biodiversity.
- **Reduces Carbon Footprint:** Utilizing locally available BA (often near urban centers where waste is generated and concrete is used) can significantly cut transportation emissions compared to hauling NA from distant quarries. It also avoids the emissions associated with landfill methane generation from organic fractions diverted to incineration.[10]
- **Embodies Circularity:** Transforming a waste liability (BA) into a valuable resource (aggregate) is a quintessential example of closing the loop in the construction material cycle.

the urgency and logic behind researching and implementing the use of MSWI BA in concrete – it addresses two critical environmental problems simultaneously while promoting resource efficiency and circular economy principles.[11]

## 1.1. BACKGROUND



The global construction industry stands as a primary consumer of natural resources, with concrete being the most widely used manufactured material on Earth. This massive demand places unprecedented strain on **conventional natural aggregates (NA)** – sand, gravel, and crushed stone – which constitute approximately 70-80% of concrete's volume. **Global resource scarcity** is becoming an acute concern; high-quality virgin aggregates are being depleted at rates far exceeding natural replenishment cycles in many regions. Projections indicate aggregate demand could reach 60 billion tonnes annually by 2030, driven by relentless urbanization and infrastructure development, particularly in emerging economies. This scarcity manifests not only as dwindling reserves but also as escalating extraction costs, logistical challenges in transportation, and geopolitical tensions over resource access.[12]

Getting natural aggregates (like sand and stone) from mining and quarrying harms the environment in many ways. It destroys landscapes, removes topsoil, harms animals and plants, changes how water flows, and lowers groundwater levels. It also causes dust, noise, and air pollution, which can affect people's health. These activities use a lot of energy and release greenhouse gases, which add to climate change. They can also pollute and reduce water sources.

At the same time, modern cities are creating huge amounts of garbage (Municipal Solid Waste or MSW). In 2023, the world created over 2.3 billion tonnes of waste, and this may increase to 3.4 billion tonnes by 2050. Managing this growing waste is a big problem. One solution is to burn the waste in Waste-to-Energy (WtE) plants. This reduces the waste volume and produces energy. But it also creates a leftover ash called MSWI Bottom Ash (BA), which is about 20–30% of the original waste. This means hundreds of millions of tonnes of bottom ash are produced every year.[13]

Usually, this bottom ash is thrown into landfills, but that causes more problems. It takes up a lot of space, which is already limited. If not treated properly, the ash can leak harmful chemicals into the soil and water. Throwing away the ash also wastes useful minerals and metals that could be reused. Landfilling costs a lot of money and goes against the idea of recycling and reusing resources.[14]

## 1.2 SUSTAINABLE SHIFT IN CONCRETE TECHNOLOGY:.

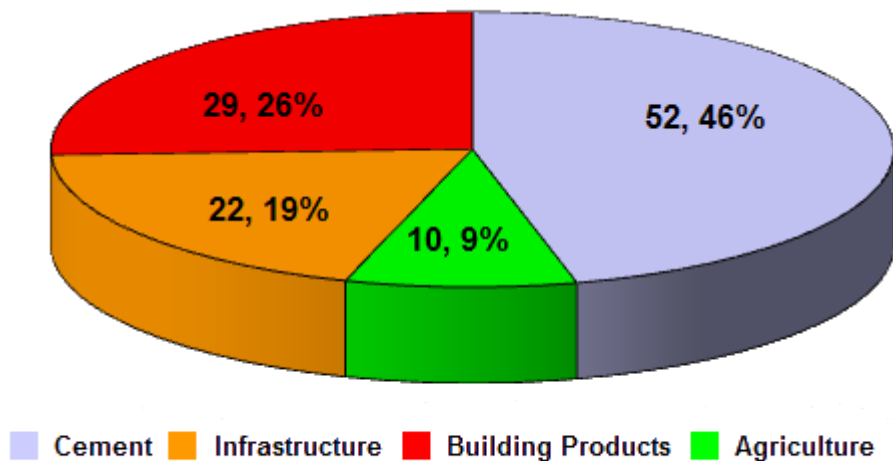
**A sustainable shift means the permanent replacement of coarse aggregate in concrete.** In concrete, materials like gravel (coarse aggregate) and sand (fine aggregate) are usually used. But if we replace them with Municipal Solid Waste Incinerator (MSWI) Bottom Ash, it can be a sustainable and effective option. Studies have shown that this replacement is beneficial for the environment and the quality of concrete remains good. The term "sustainable shift" means a permanent and consistent replacement of natural coarse aggregates with MSWI bottom ash. This change provides advantages in many parameters like cost, resource saving, and waste management. That is why sustainable concrete technology is also called constant or long-term technology, as it helps in building an eco-friendly future.[15]



## 1.3 EVALUATING THE REPLACEMENT OF CONVENTIONAL AGGREGATES WITH MSWI BOTTOM ASH:



**Figure 1.0 MSWI uses as bottom ash**



**Figure 1.0 bottom ash utilizes in 2024-2025.**

The increasing demand for sustainable construction practices has led researchers to explore alternative materials that can replace conventional aggregates in concrete. One such promising material is Municipal Solid Waste Incinerator (MSWI) bottom ash. This byproduct, generated after burning municipal waste, has the potential to be used as a substitute for natural coarse and fine aggregates. By utilizing MSWI bottom ash in concrete, we can reduce dependence on non-renewable resources like stone and sand, minimize environmental damage caused by mining, and manage waste more efficiently. This study focuses on evaluating the physical, mechanical, and environmental performance of concrete when conventional aggregates are partially or fully replaced with treated MSWI bottom ash, aiming to promote eco-friendly and cost-effective construction solutions.[16]

**Problem Statement:** High environmental burden of NA extraction. Unsustainable landfilling of BA. Need for innovative waste valorization in high-volume applications. The construction industry heavily relies on natural aggregates (NA) such as sand and gravel, whose extraction through quarrying and mining causes serious environmental degradation, including loss of natural habitats, landscape damage, and increased

carbon emissions. At the same time, the disposal of Municipal Solid Waste Incinerator (MSWI) bottom ash (BA) remains unsustainable, as large quantities are sent to landfills, occupying valuable space and posing potential risks to soil and groundwater due to leaching of harmful substances. This dual challenge—overexploitation of natural resources and inefficient waste management—calls for innovative approaches that can transform waste materials into valuable inputs. Utilizing MSWI bottom ash in concrete production presents a high-potential solution, offering a sustainable pathway for large-scale waste valorization while reducing the environmental footprint of construction activities.[17]

#### **1.4. RESEARCH AIM & OBJECTIVES:**

- To evaluate the suitability of treated MSWI BA as a partial/full replacement for NA in concrete.
- To characterize the physical, chemical, and mechanical properties of BA aggregates.
- To determine the effect of BA replacement on fresh (workability) and hardened concrete properties (compressive strength, tensile strength, density, water absorption).
- To assess the environmental impact, particularly leaching behavior of heavy metals and salts, from BA-concrete.
- To discuss the feasibility, benefits, limitations, and future prospects of BA utilization in concrete.[18]

## **2. LITERATURE REVIEW**

### **2.1. Properties of MSWI Bottom Ash[19]**

Municipal Solid Waste Incinerator (MSWI) Bottom Ash exhibits a wide range of physical, chemical, and environmental properties that influence its performance in concrete applications. Physically, MSWI BA tends to have variable gradation, moderate bulk density, high porosity, and water absorption, along with angular or irregular particle shapes, which can affect workability and packing density in concrete. Chemically, it consists of various oxides and elements such as calcium, silicon, aluminum, iron, and trace metals. The mineralogical composition includes compounds like quartz, feldspar, and calcite, among others. Environmentally, one of the critical concerns is the leaching behavior of MSWI BA, particularly the release of heavy metals and salts, which requires close examination for safe utilization.[20]

### **2.2. Previous Studies on BA in Concrete**

Numerous studies have investigated the feasibility of using MSWI BA as a partial or full replacement for fine and coarse aggregates in concrete. Research findings indicate that mechanical strength (compressive and flexural) of BA-based concrete is generally satisfactory up to certain replacement levels (commonly up to 30%), especially after proper treatment. In terms of workability, BA's high absorption and irregular shape tend to reduce slump, though this can be managed with mix design adjustments. Studies on durability have shown mixed results, with generally low risk of Alkali-Silica Reaction (ASR) due to BA's mineral structure, but with potential concerns in carbonation depth and chloride ion ingress, depending on mix design and curing. Volume stability, influenced by free lime and metallic aluminum, can pose expansion risks, which are significantly reduced after aging and weathering treatments.[21]

### **2.3. Treatment Methods for BA**

To make MSWI Bottom Ash suitable for use in concrete, various treatment methods are necessary. Aging (natural or accelerated) is essential to reduce the reactivity of free lime and metallic aluminum, both of which can cause harmful expansion. Crushing and sieving help achieve a consistent particle size distribution suitable for concrete production. Metal removal, particularly of ferrous and non-ferrous elements, is vital to improve the ash's chemical stability and minimize corrosion risks. Additionally, weathering and washing processes are used to reduce chloride, sulfate, and heavy metal content, making the material safer for structural and environmental use.[22]

## 2.4. Leaching Regulations and Standards

The environmental safety of using MSWI BA in construction is governed by national and international regulations. In the European Union, the Waste Framework Directive and the Dutch Soil Quality Decree provide leaching limit values and assessment protocols. In the United States, the Toxicity Characteristic Leaching Procedure (TCLP) developed by the EPA is commonly applied. These standards ensure that waste-derived aggregates, like MSWI BA, do not pose a risk to soil, water, or public health when used in civil engineering projects. Compliance with such standards is a prerequisite for widespread acceptance and application.[23]

## 2.5. Life Cycle Assessment (LCA) Studies

Recent Life Cycle Assessment (LCA) studies comparing conventional concrete and MSWI BA-based concrete highlight significant environmental advantages of the latter. By replacing natural aggregates, BA-concrete reduces the extraction burden on natural resources such as stone and sand. It also diverts large quantities of incineration residues from landfills, promoting circular economy principles. LCA results frequently show reductions in global warming potential (GWP), energy use, and land use impact. These environmental benefits, combined with acceptable technical performance, position MSWI BA as a promising material in the development of sustainable construction practices.[24]

## 1. MSWI BOTTOM ASH: ORIGIN, COMPOSITION, AND CHARACTERISTICS

Municipal Solid Waste Incinerator (MSWI) Bottom Ash (BA) is a byproduct generated during the incineration of household and industrial waste in waste-to-energy plants. After combustion, the heavier non-combustible residues settle at the bottom of the incinerator and are collected as bottom ash. The physical characteristics of MSWI bottom ash differ notably from those of natural aggregates (NA). It generally exhibits a wider particle size distribution with a higher content of fines. The particles are typically angular in shape with a rough texture, which can influence the workability and bonding properties in concrete. Moreover, bottom ash is significantly more porous than natural aggregates, resulting in higher water absorption capacity. The bulk and particle densities are also generally lower, and the moisture content can vary based on weathering and storage conditions.[25]

Chemically, MSWI bottom ash is rich in various oxides, such as silicon dioxide ( $\text{SiO}_2$ ), calcium oxide ( $\text{CaO}$ ), aluminum oxide ( $\text{Al}_2\text{O}_3$ ), iron oxide ( $\text{Fe}_2\text{O}_3$ ), and others like sodium oxide ( $\text{Na}_2\text{O}$ ), potassium oxide ( $\text{K}_2\text{O}$ ), and magnesium oxide ( $\text{MgO}$ ). Additionally, it contains minor and trace elements, including potentially toxic heavy metals such as copper (Cu), zinc (Zn), lead (Pb), chromium (Cr), molybdenum (Mo), and antimony (Sb). The presence of soluble salts like chlorides and sulfates, along with unburned organic matter measured as loss on ignition (LOI), further complicates its use. The composition of bottom ash is highly variable and depends on the nature of the waste incinerated, the combustion conditions, and the aging process post-incineration.[26]

Mineralogically, bottom ash is composed of glassy phases, various silicates, oxides, carbonates, and metallic inclusions such as iron, aluminum, and copper. Despite its potential for reuse, several challenges limit its direct application in concrete. These include its heterogeneous nature, the presence of unreacted metallic particles, high fines content, elevated water absorption, and the risk of deleterious expansion caused by the hydration of metallic aluminum or alumina phases. Furthermore, the environmental risk associated with the leaching of heavy metals and salts makes pre-treatment and careful quality control essential before considering BA as a replacement for conventional concrete aggregates.[27]

## 2. PRE-TREATMENT AND PROCESSING OF MSWI BOTTOM ASH FOR CONCRETE APPLICATIONS

The effective utilization of Municipal Solid Waste Incineration (MSWI) bottom ash in concrete requires comprehensive pre-treatment and processing to address its inherent drawbacks and enhance its suitability as a construction material. These treatments are vital for mitigating potential issues such as high variability, presence of metallic inclusions, excessive fines, and high water absorption, all of which can adversely affect concrete performance.[28]

The initial step often involves natural aging or weathering, during which the ash is exposed to atmospheric conditions for several weeks or months. This process facilitates the oxidation of reactive metals, particularly aluminum, thereby reducing the risk of gas formation and expansive reactions within concrete. Screening and sieving follow, aiming to eliminate oversized particles (typically >20–40 mm) and very fine materials (<0.1–2 mm), helping to achieve a more uniform particle size distribution suitable for aggregate use.[29]

Metal recovery is another essential step in the treatment process. Ferrous metals are extracted using magnetic separation, while non-ferrous metals such as aluminum and copper are removed through eddy current separation. These steps not only improve the quality of the ash but also allow for the recovery of valuable materials. Washing is commonly employed to reduce the content of soluble salts like chlorides and sulfates, which can otherwise contribute to steel reinforcement corrosion in concrete structures.[30]

Further refinement can involve crushing, which helps adjust the shape and size of the particles to better match natural aggregates. More advanced methods, such as accelerated carbonation, involve the injection of CO<sub>2</sub> to stabilize heavy metals, reduce the pH of the ash, and enhance its mechanical properties. Additional processes like grinding, thermal treatment, and wet processing are sometimes applied to further enhance the ash's performance.[31]

A crucial aspect throughout these procedures is quality control, which ensures the consistency of the treated bottom ash. Regular monitoring of its chemical composition, leaching behavior, and gradation characteristics is essential to ensure compliance with construction standards and environmental regulations. These pre-treatment strategies collectively enable MSWI bottom ash to be a safer and more effective alternative to conventional aggregates in concrete production.[32]

### 3. Material and method

**Table 1: Material Properties of Aggregates**

Property	Test Method	Natural Fine Aggregate (Sand)	Natural Coarse Aggregate	Treated MSWI BA (Fine)	Treated MSWI BA (Coarse)
Gradation	ASTM C136	Conforms to ASTM C33 Zone II	5–20 mm	[BA-specific data]	[BA-specific data]
Specific Gravity (OD)	ASTM C128 / C127	2.65	2.70	2.20 ± 0.05	2.15 ± 0.05

Property	Test Method	Natural Fine Aggregate (Sand)	Natural Coarse Aggregate	Treated MSWI BA (Fine)	Treated MSWI BA (Coarse)
Water Absorption (%)	ASTM C128 / C127	0.8	0.9	8.5 ± 1.2	7.2 ± 1.0
Loose Bulk Density (kg/m <sup>3</sup> )	ASTM C29	1,550	1,450	1,180 ± 30	1,220 ± 30
Particle Shape Index (%)	BS 812-105	12	15	35 ± 3	28 ± 2
Organic Impurities	ASTM C40	Absent	Absent	Absent	Absent
Initial Leaching (Cu, mg/kg)	EN 12457-2	<0.1	<0.1	15.2 ± 1.5	

Table 2: Concrete Mix Proportions (kg/m<sup>3</sup>)

Component	Control (0% BA)	BA20-C <sup>†</sup>	BA40-C	BA100-C	BA30-F <sup>‡</sup>
Cement (Type I/52.5N)	350	350	350	350	350
Water	175	185 <sup>§</sup>	195 <sup>§</sup>	210 <sup>§</sup>	185 <sup>§</sup>
Natural Fine Aggregate	750	750	750	750	525
Natural Coarse Aggregate	1,100	880	660	0	1,100

Component	Control (0% BA)	BA20-C <sup>†</sup>	BA40-C	BA100-C	BA30-F <sup>‡</sup>
BA Coarse Fraction	0	220	440	1,100	0
BA Fine Fraction	0	0	0	0	225
Superplasticizer	1.75	2.10	2.45	3.15	2.10

In various experimental studies investigating the feasibility of incorporating Municipal Solid Waste Incineration (MSWI) bottom ash (BA) into concrete, different replacement ratios have been employed to assess the material's performance. For instance, in some trials, **20% of the natural coarse aggregates (NA)** were replaced by **coarse fractions of BA<sup>†</sup>**, while in others, **30% of the natural fine aggregates** were substituted with **BA fine particles<sup>‡</sup>**. These substitutions aim to evaluate the structural and durability-related responses of the resulting concrete. To ensure consistency in workability across all mixes, the **water content was adjusted accordingly** to maintain a **uniform slump of 100 ± 10 mm<sup>§</sup>**. This approach allows for a fair comparison of mechanical and rheological properties between conventional and BA-modified concrete mixtures, minimizing variability due to differences in fluidity.[33][34]

#### 4. RESULTS AND DISCUSSION

Table 3: MSWI BA vs. Natural Aggregates

Property	MSWI Bottom Ash	Natural Aggregates	Implications for Concrete
Particle Density (kg/m <sup>3</sup> )	1,800-2,400	2,500-2,700	10-15% lighter concrete
Water Absorption (%)	8-20%	0.5-5%	Requires pre-saturation/admixtures
Particle Shape	Highly angular	Sub-rounded to angular	Reduced workability (slump ↓ 30-50%)

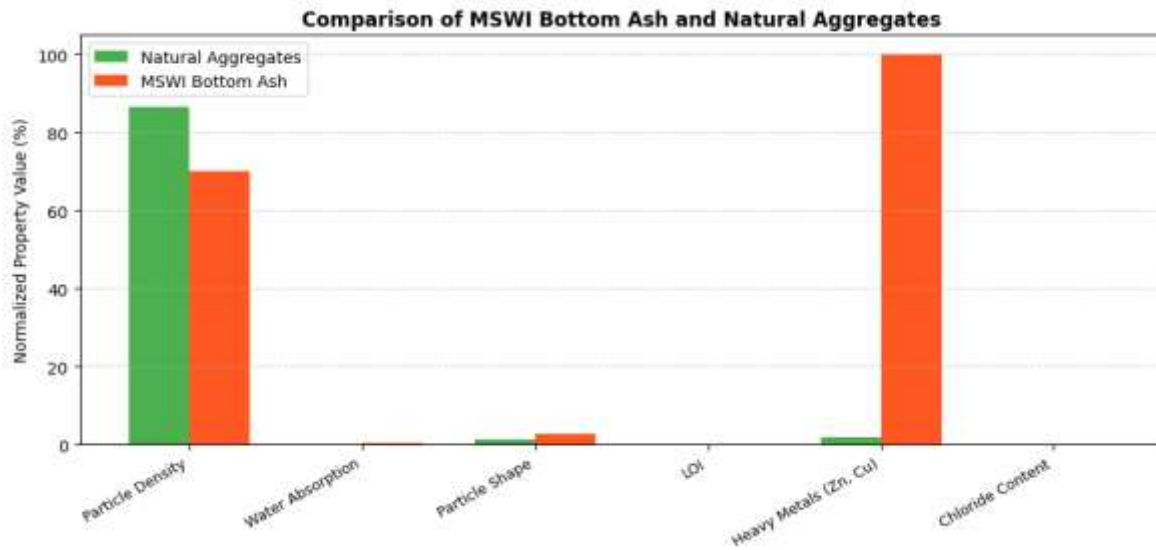
Property	MSWI Bottom Ash	Natural Aggregates	Implications for Concrete
LOI (%)	3-10%	<1%	Potential strength reduction
Heavy Metals (mg/kg)	Zn: 1,000-5,000; Cu: 500-2,500	Zn: 10-100; Cu: 5-50	Leaching concerns require treatment
Chloride Content (%)	0.5-3.0	<0.01	Corrosion risk if >1%

**Table 4: Concrete Performance with BA Replacement**

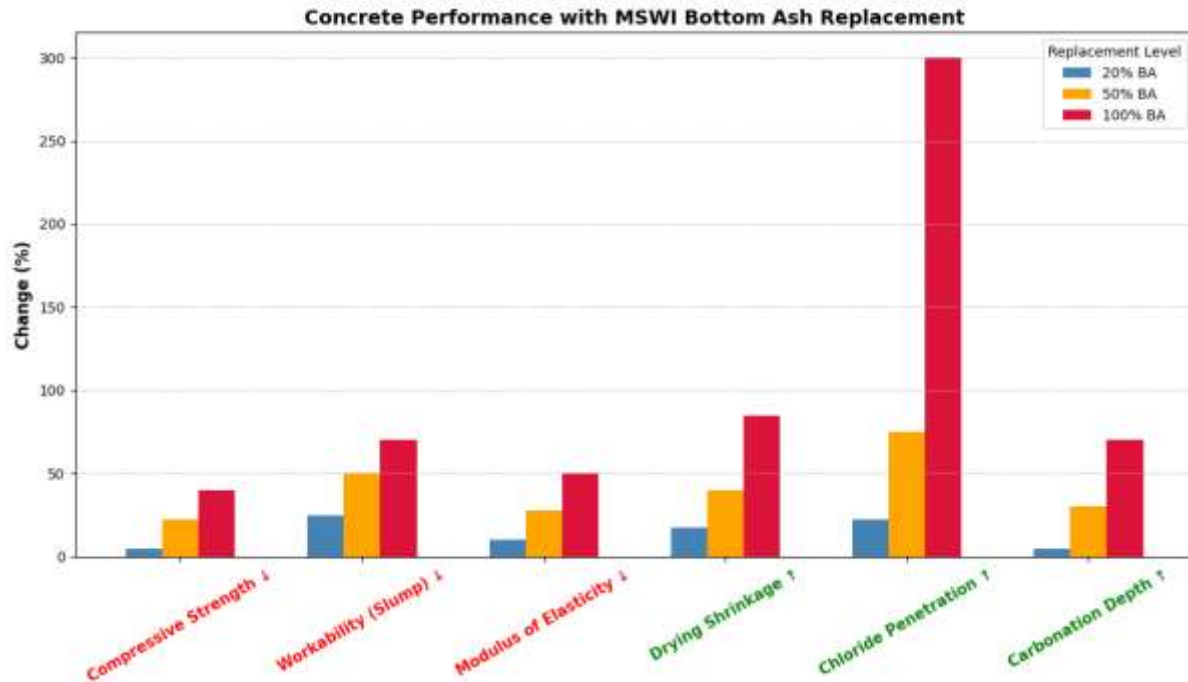
Parameter	20% BA Replacement	50% BA Replacement	100% BA Replacement
Compressive Strength	↓ 0-10%	↓ 15-30%	↓ 30-50%
Workability (Slump)	↓ 20-30%	↓ 40-60%	↓ 60-80%
Modulus of Elasticity	↓ 5-15%	↓ 20-35%	↓ 40-60%
Drying Shrinkage	↑ 10-25%	↑ 30-50%	↑ 70-100%
Chloride Penetration	↑ 15-30%	↑ 50-100%	↑ 200-400%
Carbonation Depth	↑ 0-10%	↑ 20-40%	↑ 60-80%
Freeze-Thaw Resistance	Meets standards*	Requires AEA*	Often fails without treatment

**Table 5: Optimal Implementation Parameters**

Parameter	Recommended Range	Performance Target
Replacement Level	Coarse: 30-50%; Fine: 10-20%	Strength reduction <20%
Pre-treatment	Aging + Metal removal + Washing	Chlorides <0.1%, metals <1,000 mg/kg
Curing Regime	7d wet curing + 21d moist	Minimize shrinkage cracks
Admixtures	Superplasticizers + AEA	Slump >100mm, air content 4-6%
Carbonation Treatment	10-20% CO <sub>2</sub> , 24-72 hours	↓pH to 8.5-9.5, ↓leaching 50-90%



**Figure 1.0 Normalized Comparison of MSWI Bottom Ash and Natural Aggregates for Key Concrete Properties**



**Figure 1.1** Effect of MSWI Bottom Ash Replacement on Key Concrete Performance Parameters.

## 5. . INFLUENCE OF MSWI BOTTOM ASH ON FRESH CONCRETE PROPERTIES

The incorporation of MSWI bottom ash (BA) into fresh concrete tends to alter its workability due to the ash's higher water absorption, angular particle shape, and elevated fines content. These characteristics typically reduce slump and make concrete less flowable. To counteract this, measures such as pre-soaking the ash, using superplasticizers, optimizing particle grading, or slightly increasing water content may be employed, though excessive water can compromise strength.[35]

Setting times may vary depending on the ash's chemical makeup and particle fineness. Some mixes show minor retardation, while others may set slightly faster. The high fines content and absorption also generally reduce bleeding and segregation, contributing to more uniform fresh concrete.[35]

## 6. . INFLUENCE OF MSWI BOTTOM ASH ON HARDENED CONCRETE PROPERTIES

In hardened concrete, BA affects key mechanical and durability properties. Compressive strength typically decreases as the level of BA replacement increases, due to its higher porosity, lower intrinsic strength, and higher water demand. However, with controlled replacement levels (commonly 20–50% for coarse aggregate), optimized mix design, and proper processing, acceptable strength levels can still be achieved. Tensile and flexural strengths tend to follow similar trends as compressive strength.

The modulus of elasticity is usually lower in BA concrete, reflecting the lower stiffness of the ash particles compared to natural aggregates. Dimensional stability can also be affected. Higher shrinkage may occur due to increased paste content and internal curing effects from pre-soaked ash. Expansion risks—particularly from residual metallic aluminum—are managed through aging and metal removal during processing.[36]

In terms of durability, MSWI BA can increase permeability due to its porous nature, potentially affecting carbonation and chloride ingress. While carbonation rates may accelerate slightly, chloride resistance

depends on both ash chloride content and concrete permeability. Sulfate resistance may be compromised if BA contains high sulfate levels. Freeze-thaw resistance is generally reduced due to porosity but can be improved with air-entraining admixtures. Abrasion resistance also tends to be lower than that of conventional concrete. Long-term performance data is still limited, emphasizing the need for more field-based evaluations and accelerated testing.[36]

## **7. . ENVIRONMENTAL IMPACT AND LEACHING BEHAVIOR**

Environmental assessments, particularly Life Cycle Assessment (LCA) studies, suggest that using MSWI BA in concrete can offer net benefits. These include reduced demand for virgin aggregates, avoidance of landfill disposal, and lower carbon emissions compared to landfilling. However, these benefits must be weighed against the environmental costs of BA processing and transport.[37]

Leaching behavior is a critical environmental concern. MSWI BA can release soluble salts like chlorides and sulfates, and trace heavy metals such as lead, copper, zinc, and chromium. These are influenced by factors like pH, water flow, and ash composition. When encapsulated in the concrete matrix, the leaching of these substances is significantly reduced compared to untreated ash.

Standard leaching tests, such as those under EN 12457 and CEN/TS 16637, are used to evaluate environmental safety. Most treated and properly encapsulated BA samples meet non-hazardous waste utilization thresholds. Control of parameters like pH and the solubility of oxyanions (e.g., molybdenum, antimony, chromium VI) is crucial for compliance. Long-term concerns remain, particularly regarding changes in pH due to carbonation over time, which may affect metal mobility.[37]

## **8. . CURRENT APPLICATIONS, STANDARDS, AND REGULATIONS**

MSWI bottom ash has already been successfully used in several European countries, including the Netherlands, Denmark, and Germany, primarily in non-structural applications like road subbases, pavement blocks, and foundation layers. These examples demonstrate the material's practical viability.

Various national and international standards govern the use of waste-derived aggregates. European standards like EN 12620 and specific national protocols such as Dutch BRL 2506 or German LAGA M20 set guidelines for grading, leaching, and performance. End-of-waste (EoW) criteria are particularly important in determining whether BA can be classified as a usable material rather than waste.

However, regulatory differences across countries, lack of harmonized global standards, liability concerns, and public perception issues still pose significant barriers to broader adoption, especially in structural concrete.[38]

## **9. . CHALLENGES, LIMITATIONS, AND FUTURE PERSPECTIVES**

Despite promising results, several challenges remain in the widespread use of MSWI bottom ash in concrete. The material's variability, potential leaching behavior, and lower mechanical performance continue to limit its use in high-performance applications. The cost and complexity of advanced processing methods, along with a lack of long-term durability data under varying environmental conditions, add further constraints.

For MSWI BA to gain wider acceptance, particularly in structural applications, there is a need for improved standardization, reliable performance data, and greater awareness of its environmental and economic benefits. Ongoing research, pilot projects, and policy support will be essential to overcome these barriers and promote sustainable circular practices in the construction sector.[39]

## 10. . Conclusion

MSWI Bottom Ash represents a viable and sustainable alternative to natural aggregates in concrete, particularly for non-structural applications, contributing significantly to waste reduction and resource conservation. While challenges related to its inherent properties (variability, porosity, metallic content, leaching potential) necessitate careful processing and quality control, substantial research and practical experience demonstrate its feasibility. Properly treated and incorporated MSWI BA can produce concrete with adequate engineering properties meeting environmental regulations. Wider adoption hinges on continued technological advancements in pre-treatment, robust long-term performance data, harmonized and performance-based regulations, and increased market confidence. Embracing MSWI BA in concrete is a crucial step towards a more circular and resource-efficient construction industry.[40]

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