# Effect of Partial Replacement of Ordinary Portland Cement With Incinerated Sewage Sludge Ash On The Performance Of M20 Concrete

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**Abstract** - *The experimental investigation on the incorporation of Incinerated Sewage Sludge Ash (ISSA) into concrete mixes has yielded significant insights into its impact on workability, mechanical properties, and durability. The primary objective was to evaluate the impact of ISSA on the slump and workability of fresh concrete mixes. Results showed that the inclusion of ISSA up to 30% resulted in a slight increase in workability, with the slump value reaching its peak at 10% ISSA (75 mm). Beyond this point, the slump values stabilized or slightly decreased, indicating that ISSA content up to 30% does not adversely affect workability. To assess the influence of ISSA on the mechanical properties of hardened concrete, including compressive, flexural, and tensile strength. Compressive strength tests revealed a general decline with increasing ISSA content. The normal mix (0% ISSA) reached 30 MPa at 28 days, while Mix 1 (10% ISSA) exceeded this, achieving 31 MPa. However, higher ISSA content resulted in reduced compressive strengths, with Mix 4 (40% ISSA) showing the lowest at 26 MPa. Flexural and split tensile strength tests mirrored these results, with Mix 1 (10% ISSA) closely matching or slightly surpassing the normal mix, while higher ISSA contents led to progressively lower strengths.*

***Key Words*: Ordinary Portland Cement, Incinerated, Sewage Sludge Ash, compressive, flexural, and tensile strength.etc**

## 1. INTRODUCTION

Concrete is amongst broadly utilized construction materials globally, primarily comprises of cement, water, and aggregates (sand, gravel, or crushed stone). Over time, researches have been conducted for enhancing its properties and sustainability by integrating various SCMs. Amongst is Incinerated Sewage Sludge Ash (ISSA), derived from the incineration of sewage sludge. ISSA is a by-product obtained from the incineration of sewage sludge, which is the residual, semi-solid material produced as a by-product of wastewater treatment processes. The incineration process reduces the volume of sludge and converts it into ash, which can then be used in various applications, including as an SCM in concrete.

### 1.1 Benefits of ISSA in Concrete

- Improved Strength ISSA contains high levels of silica, alumina, and calcium, which contribute to the pozzolanic reaction, enhancing compressive strength of concrete over time.
- Durability The incorporation of ISSA in concrete improves its resistance to sulfate attacks, chloride penetration, and other chemical attacks, enhancing the overall durability of the concrete.
- Reduced Permeability ISSA can reduce the permeability of concrete, decreasing the risk of water ingress and subsequent deterioration due to freeze-thaw cycles or other environmental factors.
- Waste Management Utilizing ISSA in concrete provides a sustainable solution for disposing of sewage sludge, reducing the environmental impact of waste management.
- Cost Savings ISSA can partially replace traditional cement and aggregates, potentially lowering material costs in concrete production.
- Sustainability By using ISSA, mandate for natural sources like limestone (used in cement production) and natural aggregates is reduced, promoting more sustainable construction practices.
- Thermal Conductivity The inclusion of ISSA could enhance thermal insulation properties of concrete. 3 Low thermal conductance implies better thermal insulation, making buildings more energy-efficient by reducing the need for heating and cooling.

### 1.2 Applications of ISSA in Concrete

- General Construction ISSA can be used in various types of concrete for general construction purposes, including residential, commercial, and industrial buildings.
- Road Construction It can be utilized in the construction of roadways, including pavements, sidewalks, and other infrastructure projects.
- Precast Concrete Products ISSA can be used in the production of precast concrete products such as blocks, pipes, and panels.
- Marine Structures Due to its enhanced durability and resistance to chemical attacks, ISSA-incorporated concrete is suitable for marine structures exposed to harsh environments.

### 1.3 Objectives for Investigating the Properties of Concrete with ISSA

- The first objective is for evaluating impact of ISSA on the slump and workability of fresh concrete mixes, focusing on changes in consistency and necessary adjustments in the mix design to maintain desired workability.
- The second objective is to assess effect of ISSA upon mechanical properties of hardened concrete, including Compressive, flexural, and tensile strength, by conducting standardized tests and analyzing trends over time.
- The third objective is to investigate the thermal resistance of concrete containing ISSA, examining its thermal conductivity, heat resistance, to determine its suitability for high-temperature applications.
- The fourth objective is to explore the environmental benefits of incorporating ISSA in concrete mixtures. This includes evaluating the potential for ISSA to reduce the carbon footprint of concrete production through usage of industrial by-products, & examining its role in promoting the recycle of waste materials and supporting circular economy principles in construction practices.

## 2. Mix Design for M20 Concrete with ISSA

The mix design involves varying ISSA content and adjusting proportions accordingly. Below are the different mixes designed for this study:-

**Table 1:-** Mix Proportion

| Mix Design | OPC | ISSA | Fine Agg. | Coarse Agg. | Water | W/C Ratio |
|---|---|---|---|---|---|---|
| **Normal mix 0%** | 100% | 0% | 1.25 | 2.75 | 0.55 | 0.55 |
| **Mix 1** | 90% | 10% | 1.25 | 2.75 | 0.55 | 0.55 |
| **Mix 2** | 80% | 20% | 1.25 | 2.75 | 0.55 | 0.55 |
| **Mix 3** | 70% | 30% | 1.25 | 2.75 | 0.55 | 0.55 |
| **Mix 4** | 60% | 40% | 1.25 | 2.75 | 0.55 | 0.55 |

### 2.1 Experimental Results

**Table:-2** Slump Values test

| Mix Designation | Slump (mm) |
|---|---|
| Normal mix 0% – 0% | 70 |
| Mix 1 (10% ISSA) | 75 |
| Mix 2 (20% ISSA) | 72 |
| Mix 3 (30% ISSA) | 72 |
| Mix 4 (40% ISSA) | 70 |

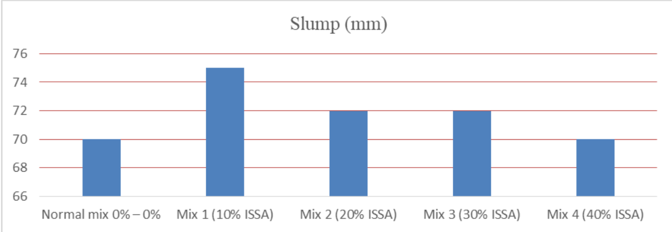
**Importance**

- **Workability**

The slump test measures the workability or consistency of fresh concrete. It is crucial for ensuring that the concrete mix has the desired consistency for proper placement and compaction.

- **Impact of ISSA (Iron and Steel Slag Aggregate)**

Slump values for mixes containing ISSA are similar to or slightly high than Normal mix 0%, indicating that ISSA does not significantly affect the workability of the concrete. This is important for ensuring that the addition of ISSA does not negatively impact the handling and placement of the concrete.




**Graph 1:-** Slump Value

### 2.2 Mechanical Properties

**i. Compressive Strength (MPa)**

**Table:-2** compressive strength test

| Mix Designation | 7 Days | 14 Days | 28 Days |
|---|---|---|---|
| Normal mix 0% | 20 | 26 | 30 |
| Mix 1 (10% ISSA) | 18 | 24 | 31 |
| Mix 2 (20% ISSA) | 16 | 22 | 28 |
| Mix 3 (30% ISSA) | 14 | 20 | 27 |
| Mix 4 (40% ISSA) | 12 | 18 | 26 |

- **Initial Strength Development**

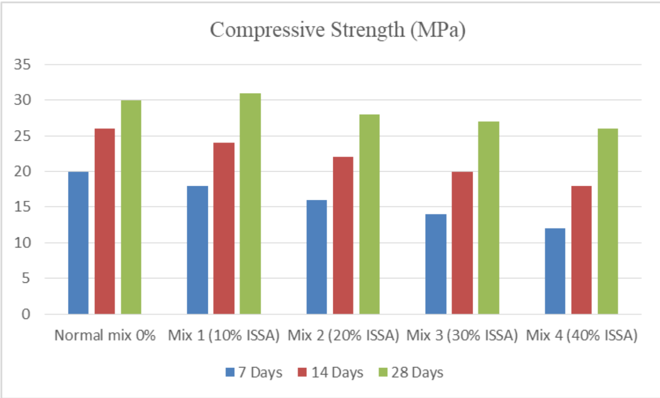
The normal mix demonstrates higher compressive strength at all ages compared to mixes with ISSA. This indicates that the inclusion of ISSA might delay the rate of strength gain in the early stages (7 and 14 days).

- **Long-Term Strength**

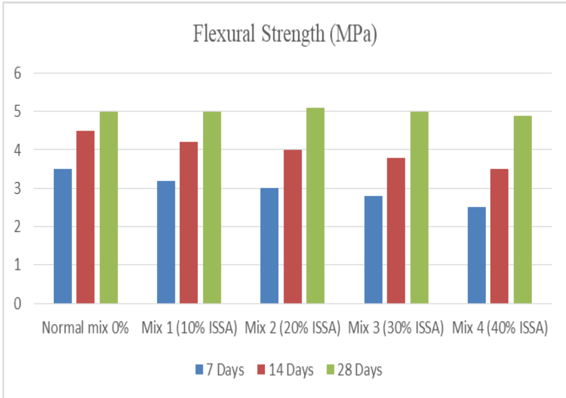
Mix 1 with 10% ISSA shows the highest compressive strength at 28 days, suggesting that a lower percentage of ISSA could potentially improve long-term strength development, whereas higher percentages (30% and 40%) might reduce strength over time.

**Fig;-1** Compressive Testing Machine

**Fig;-2** Compressive Strength




**Graph:-2** compressive strength




**Graph:-3** Flexural strength

### ii. Flexural Strength (MPa)

**Table:-3** Flexural Strength test

| Mix Designation | 7 Days | 14 Days | 28 Days |
|---|---|---|---|
| Normal mix 0% | 3.5 | 4.5 | 5.0 |
| Mix 1 (10% ISSA) | 3.2 | 4.2 | 5.0 |
| Mix 2 (20% ISSA) | 3.0 | 4.0 | 5.1 |
| Mix 3 (30% ISSA) | 2.8 | 3.8 | 5.0 |
| Mix 4 (40% ISSA) | 2.5 | 3.5 | 4.9 |

- **Strength Reduction**

  There's general trend of decreased flexural strength with high ISSA content, particularly in early curing stages (7 and 14 days). This suggests that higher percentages of ISSA might negatively impact the flexural properties of concrete in the short term.

- **Comparable Long-Term Strength**

  At 28 days, the flexural strength of mixes with ISSA is relatively close to the normal mix, indicating that the long-term performance might be acceptable, but care should be taken in applications where early-age strength is critical.

**Fig;-3** Flexural Testing Machine **Fig;-4** Flexural Strength

### iii. Split Tensile Strength (MPa)

**Table:-3** Split Tensile Strength test

| Mix Designation | 7 Days | 14 Days | 28 Days |
|---|---|---|---|
| Normal mix 0% | 2.2 | 2.8 | 3.2 |
| Mix 1 (10% ISSA) | 2.0 | 2.6 | 3.1 |
| Mix 2 (20% ISSA) | 1.8 | 2.4 | 2.9 |
| Mix 3 (30% ISSA) | 1.6 | 2.2 | 2.7 |
| Mix 4 (40% ISSA) | 1.4 | 2.0 | 2.7 |

- **Decrease in Tensile Strength**

  It reduces with increasing ISSA content. Indicating high % of ISSA may lead to lower resistance to tensile stresses, which could be crucial factor in structure based uses where tensile strength is important.

**Fig;-5** Split Tensile Strength

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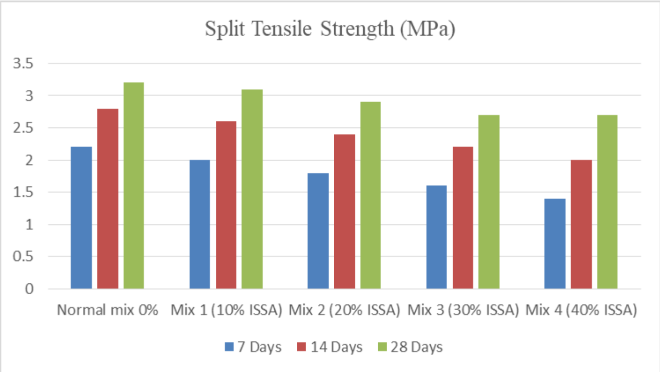



**Graph:-4** Split Tensile Strength

iv. **Durability test - acid attack test**

A simple test to evaluate the chemical resistance of concrete with ISSA is the **acid attack test.** This test involves exposing concrete samples to an acidic environment and measuring the changes in mass, strength, and appearance over time. Here's a step-by-step procedure

a. **Materials**

- Concrete samples with and without ISSA.
- Acid solution (commonly used acids include sulfuric acid ($H_2SO_4$) or hydrochloric acid (HCl).
- Plastic containers.
- Weighing scale.

b. **Procedure**

- **Sample Preparation**
  - Prepare concrete samples having diverse % of ISSA (e.g., 0%, 10%, 20%, 30%, and 40% ISSA).
  - Cure the concrete samples for 28 days under standard conditions.
- **Initial Measurements**
  - Measure the initial mass of each concrete sample using a weighing scale.
  - Record the initial mass ($M_0$) of each sample.
- **Acid Solution Preparation**
  - Prepare an acid solution with a specific concentration (e.g., 3% sulfuric acid or 3% hydrochloric acid by volume).
  - Ensure the solution is well-mixed and maintain a consistent concentration throughout the test.
- **Immersion**
  - Immerse the concrete samples in the acid solution, ensuring they are fully submerged.
  - Keep the samples in the acid solution for a specific duration, typically 28 days.
- **Periodic Observations**
  - Periodically (e.g., every 7 days), remove the samples from the acid solution and rinse them with distilled water.
  - Observe and record any visible changes in the surface of the samples (e.g., discoloration, surface degradation).
- **Final Measurements**
  - After the test duration, remove the samples from the acid solution, clean properly with distilled water, and allow them to dry.
  - Measure the final mass of each sample using the weighing scale.
  - Record the final mass ($M_1$) of each sample.
- **Calculations**
  - Calculate % mass loss for every sample using the formula

$$\text{Mass loss (\%)} = \frac{M0 - M1}{M0} \times 100$$

Where, Initial mass ($M_0$), Final mass ($M_1$)

| Mix | ISSA Replacement (%) | Initial Mass ($M_0$) (grams) | Final Mass ($M_1$) (grams) | Mass Loss (%) |
|---|---|---|---|---|
| Mix 1 | 10 | 8100 | 7950 | 1.85 |
| Mix 2 | 20 | 8110 | 7920 | 2.34 |
| Mix 3 | 30 | 8140 | 7880 | 3.19 |
| Mix 4 | 40 | 8115 | 7850 | 3.27 |

**Importance**

- **Durability**

  Mass loss measurements can indicate the stability & durability of concrete mix. Higher mass loss might be associated with increased porosity or degradation, which could affect concrete life.
- **Quality Assessment**

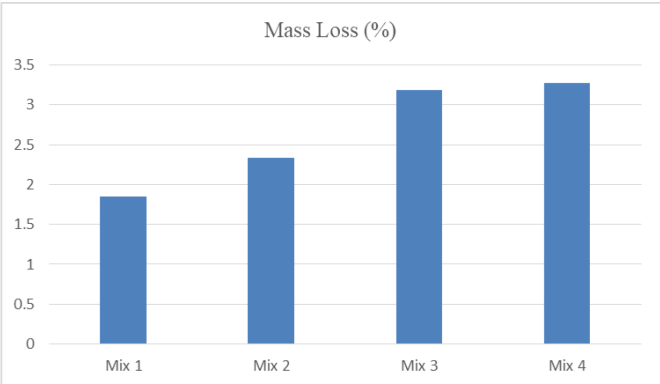
  Assessing mass loss is crucial for understanding the long-term performance of concrete mixes, particularly in environments where erosion or other forms of material loss might be a concern.

**Fig;-6** Initial Mass of the Sample

**Fig;-7** Sample Immersed In Acid Solution

**Fig;-8** Sample Fully Submerged In Acid Solution

**Fig;-9** Periodic Curing Of Sample




**Graph:-5** Mass Loss (%)

## 3. Results and Discussion

### 1) Slump values

The slump values for every mix indicate that the workability of concrete increases slightly with ISSA up to 30%, remaining stable beyond that:

- **Normal mix (0% ISSA)** 70 mm
- **Mix 1 (10% ISSA)** 75 mm
- **Mix 2 (20% ISSA)** 72 mm
- **Mix 3 (30% ISSA)** 72 mm
- **Mix 4 (40% ISSA)** 70 mm

The increase in slump values with 10% ISSA indicates improved workability, which can be beneficial for certain construction applications.

### 2) Compressive Strength

Compressive strength of various concrete mixes was evaluated at 7, 14, and 28 days. Results indicate a general trend of decrease in compressive strength with increase in ISSA content

- **Normal Mix (0% ISSA)**
  The compressive strength increased consistently over time, reaching 30 MPa at 28 days
- **Mix 1 (10% ISSA)**
  Showed a slightly lower strength at 7 and 14 days compared to the normal mix but surpassed the normal mix at 28 days with 31 MPa.
- **Mix 2 (20% ISSA)**
  Demonstrated a further reduction in early strength but achieved a respectable 28 MPa at 28 days.
- **Mix 3 (30% ISSA) and Mix 4 (40% ISSA)**
  Both mixes exhibited progressively lower strengths at all tested ages, with Mix 4 having the lowest compressive strength of 26 MPa at 28 days.

### 3) Flexural Strength

The flexural strength results show similar trends to the compressive strength

- **Normal Mix (0% ISSA)**
  Achieved a steady increase, reaching 5.0 MPa at 28 days.
- **Mix 1 (10% ISSA)**
  Slightly lower than the normal mix initially but equaled it at 28 days with 5.0 MPa.
- **Mix 2 (20% ISSA)**
  Showed a minor increase at 28 days (5.1 MPa), surpassing both the normal mix and Mix 1.
- **Mix 3 (30% ISSA) and Mix 4 (40% ISSA)**
  Both mixes had lower flexural strengths, with Mix 4 showing a decrease to 4.9 MPa at 28 days.

### 4) Split Tensile Strength

The split tensile strength results follow the trend seen in compressive and flexural strengths:

- **Normal Mix (0% ISSA)**
  Highest tensile strength, reaching 3.2 MPa at 28 days.
- **Mix 1 (10% ISSA)**
  Slightly lower than the normal mix but close at 3.1 MPa at 28 days.
- **Mix 2 (20% ISSA)**
  Lower than Mix 1, achieving 2.9 MPa at 28 days.
- **Mix 3 (30% ISSA) and Mix 4 (40% ISSA)**
  Both showed decreasing strengths, with Mix 4 achieving 2.7 MPa at 28 days.

### 5) Acid Attack Test

The acid attack test results indicate the durability of concrete mixes in acidic environments:

- **Mix 1 (10% ISSA)**
  Showed the least mass loss (1.85%), indicating good resistance to acid attack.
- **Mix 2 (20% ISSA)**
  Experienced slightly higher mass loss (2.34%).
- **Mix 3 (30% ISSA) and Mix 4 (40% ISSA)**
  Had progressively higher mass losses, with Mix 4 experiencing the highest at 3.27%.

## 4. CONCLUSIONS

The experimental investigation on the incorporation of Incinerated Sewage Sludge Ash (ISSA) into concrete mixes did offer substantial perceptions in its impact on workability, mechanical properties, and durability.

- **Slump Values**

Adding ISSA up to 30% lead to slight increase in workability, with the slump value reaching its peak at 10% ISSA (75 mm). Beyond this point, the slump values stabilized or slightly decreased, indicating that ISSA content up to 30% does not adversely affect the workability of the concrete.

- **Compressive Strength**

Compressive strength tests revealed a general decline with increasing ISSA content. The normal mix (0% ISSA) reached 30 MPa at 28 days. Mix 1 (10% ISSA) exceeded this, achieving 31 MPa at 28 days, showing an initial slight decrease but eventual strength gain. However, mixes with higher ISSA content (20% and above) showed reduced compressive strengths, with Mix 4 (40% ISSA) having the lowest at 26 MPa at 28 days.

- **Flexural Strength**

The trend in flexural strength mirrored the compressive strength results. The normal mix achieved 5.0 MPa at 28 days. Mix 1 (10% ISSA) matched this performance, and Mix 2 (20% ISSA) slightly surpassed it at 5.1 MPa. Higher ISSA contents (30% and 40%) resulted in reduced flexural strengths, with Mix 4 decreasing to 4.9 MPa at 28 days.

- **Split Tensile Strength**

The split tensile strength also followed the trend observed in compressive and flexural strengths. The normal mix reached the highest tensile strength of 3.2 MPa at 28 days. Mix 1 (10% ISSA) closely followed with 3.1 MPa, while higher ISSA contents led to progressively lower strengths, with Mix 4 (40% ISSA) at 2.7 MPa at 28 days.

- **Acid Attack Resistance**

Durability tests under acidic conditions highlighted Mix 1 (10% ISSA) as having the least mass loss (1.85%), indicating superior resistance to acid attack. Higher ISSA contents resulted in increased mass losses, with Mix 4 (40% ISSA) experiencing the highest mass loss at 3.27%.

### 4.1 Final Statement

Based on the comprehensive analysis of the experimental results, Mix 1 (10% ISSA) emerges as the best overall performer. It not only demonstrated the highest compressive and flexural strengths at 28 days compared to other mixes but also exhibited the least mass loss in the acid attack test, indicating excellent durability.

The significance of utilizing ISSA in concrete lies in its ability to partially replace cement, offering both environmental and economic benefits. This study confirms that up to 10% ISSA replacement is feasible without significantly compromising the mechanical properties and durability of concrete. Adopting ISSA can help the concrete industry reduce reliance on traditional cement, lower carbon emissions, and find a beneficial use for waste materials, contributing to more sustainable construction practices.

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