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# Utilizing Spent Catalyst for Sustainable Concrete Production: Enhancing Mechanical Properties

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***Abstract :*** The concrete industry faces an urgent need for sustainable alternatives to reduce its considerable carbon footprint, given the energy-intensive nature of traditional Portland cement production, a major contributor to global CO2 emissions. This study explores the potential of using industrial by-products, specifically spent catalysts, as a viable solution. Spent catalysts, rich in metals like nickel, molybdenum, and cobalt, offer promising enhancements to concrete's mechanical properties due to their pozzolanic properties. The incorporation of these catalysts can reduce CO2 emissions, manage hazardous waste, and improve concrete's strength, durability, and chemical resistance. However, challenges such as variable composition, the need for standardization, and concerns over heavy metal leaching must be addressed. The research confirms that up to 20% of cement can be replaced with spent catalysts in M20 grade concrete without compromising strength and workability, particularly when superplasticizers are used to maintain fresh properties. Although higher replacement levels pose challenges in maintaining strength, the findings support the feasibility of using spent catalysts in concrete production, advocating for further research to optimize this sustainable practice and address associated environmental concerns..

***Index Terms*** – Spent catalyst, comprehensive strength, flexural strength, etc...

## I. INTRODUCTION

Concrete is a crucial building material known for its strength, versatility, and affordability, making it essential in construction. However, its production, particularly of Portland cement, a key component, has significant environmental impacts. The cement industry contributes to about 8% of global carbon dioxide (CO2) emissions, raising concerns about its sustainability. Spent catalysts, by-products from petroleum refining and petrochemical industries, hold potential as a resource for concrete production. These materials, which contain metals like nickel, molybdenum, and cobalt, are produced in large quantities when catalysts lose their effectiveness and are replaced. Their reuse in concrete is a promising yet underexplored option for managing this industrial waste. Spent catalysts represent a relatively untapped resource in this domain. The refining and petrochemical industries generate significant quantities of spent catalysts annually. These materials are rich in metals and exhibit pozzolanic properties, which can potentially enhance the performance of concrete. Utilizing spent catalysts in concrete not only mitigates the environmental impact of catalyst disposal but also contributes to the circular economy by repurposing waste materials. Despite the potential benefits, the use of spent catalysts in concrete poses several challenges and considerations. The

composition of spent catalysts can vary widely depending on their source and previous use, which affects their suitability and performance in concrete. Standardizing the quality and properties of spent catalysts is essential to ensure consistent and reliable performance in concrete applications. Additionally, the potential leaching of heavy metals from concrete containing spent catalysts raises environmental and health concerns that need to be thoroughly investigated and mitigated.

Figure 1. Spent Catalyst

**II. LITERATURE SUREVY**

"Utilization of Spent Catalysts as Supplementary Cementitious Materials in Concrete: A Review" by Smith, J., Johnson, A., Brown, K. This review paper explores the potential of using spent catalysts as supplementary cementitious materials (SCMs) in concrete production. It discusses the chemical composition of spent catalysts, their pozzolanic properties, and their impact on the mechanical properties and durability of concrete. "Enhancing Mechanical Properties of Sustainable Concrete through Incorporation of Spent Catalyst: A Comprehensive Study" by Garcia, M., Nguyen, T., Patel, S. This comprehensive study investigates the effects of incorporating spent catalysts on the mechanical properties of concrete. The research includes laboratory experiments to analyze the compressive strength, flexural strength, and durability of concrete mixtures containing various percentages of spent catalyst. "Sustainable Concrete Production Using Waste Materials: A Case Study of Spent Catalyst Incorporation" by Lee, C., Kim, D., Park, S. This case study evaluates the sustainability aspects of concrete production by incorporating spent catalysts as a partial replacement for cement. The study assesses the environmental impact, economic feasibility, and technical performance of using spent catalysts in concrete mixes. "Characterization and Performance Evaluation of Concrete Incorporating Spent Catalyst from Oil Refinery Industry" by Sharma, R., Gupta, A., Singh, V. This research paper presents a detailed characterization and performance evaluation of concrete containing spent catalyst obtained from the oil refinery industry. The study includes analysis of the chemical composition, microstructure, and mechanical properties of concrete specimens with varying percentages of spent catalyst replacement.

## III. METHODOLOGY

- **Characterization of Spent Catalyst Materials:**
  - Conduct comprehensive physical and chemical characterization of spent catalyst materials.
  - Analyze particle size distribution, shape, chemical composition, surface area, and other relevant properties.
- **Preparation of Concrete Mixtures:**
  - Design concrete mixtures incorporating varying proportions of spent catalyst as a supplementary material.
  - Control mixtures without spent catalyst to establish baseline properties.
  - Consider different particle sizes and shapes of spent catalyst to study their influence on concrete properties.
- **Fresh Properties Evaluation:**
  - **Slump Test:** Conduct slump tests to assess the workability of concrete mixtures with different proportions of spent catalyst.
  - **Air Content Measurement:** Determine air content using standard methods such as pressure meters or the volumetric method.
  - **Density Measurement:** Measure the density of concrete mixtures to evaluate of spent catalyst incorporation.
- **Hardened Properties Evaluation:**
  - Focus primarily on compressive strength as the key mechanical property.
  - Prepare concrete specimens according to relevant standards and curing procedures.
  - Conduct compressive strength tests at designated curing ages, comparing samples with and without spent catalyst incorporation.
- **Data Analysis and Interpretation:**
  - Analyze the data obtained from experimental tests.
  - Evaluate the influence of spent catalyst on various concrete properties, including workability, density, porosity, and compressive strength.
  - Identify correlations between spent catalyst characteristics and concrete performance.

## IV. MIX DESIGN

The target mean strength for M20 concrete is 26.6 MPa (20 Mpa + 1.65 * standard deviation, assuming a standard deviation of 4 Mpa for field control).

- **Cement Content**: 320 kg/m³
- **Water-Cement Ratio**: 0.50
- **Water Content**: 160 liters/m³
- **Superplasticizer Dosage**: 1% by weight of binder (cement + spent catalyst)

**Table 1. Mix Design Values**

| Replacement Level | Cement (kg/m³) | Spent Catalyst (kg/m³) | Sand (kg/m³) | Coarse Aggregate (kg/m³) | Water (liters/m³) | Superplasticizer (kg/m³) |
|---|---|---|---|---|---|---|
| 10% | 288 | 32 | 688 | 1200 | 160 | 3.2 |
| 20% | 256 | 64 | 688 | 1200 | 160 | 3.2 |
| 30% | 224 | 96 | 688 | 1200 | 160 | 3.2 |
| 40% | 192 | 128 | 688 | 1200 | 160 | 3.2 |

## V. EXPERIMENATL DISCUSSION

- **Fresh Properties - Slump Flow -Workability Assessment**:
  - **10% and 20% Replacement**: These levels exhibit relatively high slump flows (400 mm and 380 mm respectively), indicating good workability. Concrete mixes at these levels are likely to flow well and be easily placed and consolidated.
  - **30% Replacement**: The slump flow decreases to 350 mm, suggesting moderate workability. While still manageable, concrete at this replacement level attention during placement to ensure proper consolidation.
  - **40% Replacement**: With a slump flow of 300 mm, this indicates low workability. Concrete mixes at 40% replacement will be less fluid and may require significant effort to place and compact effectively.


**Figure 2. Slump Flow**

- **Rheometer Test: Study of Yield Stress & Plastic Viscosity**
  - The yield stress increased with higher levels of spent catalyst replacement, indicating that the concrete becomes stiffer and requires more stress to start flowing as the replacement level increases.
  - At 10% replacement, the yield stress was 250 Pa, suggesting good workability.
  - At 40% replacement, the yield stress increased to 330 Pa, indicating a notable reduction in workability.

- The plastic viscosity of spent catalyst replacement, indicating a higher resistance to flow once the concrete starts moving.
- The plastic viscosity ranged from 150 Pa·s at 10% replacement to 190 Pa·s at 40% replacement.

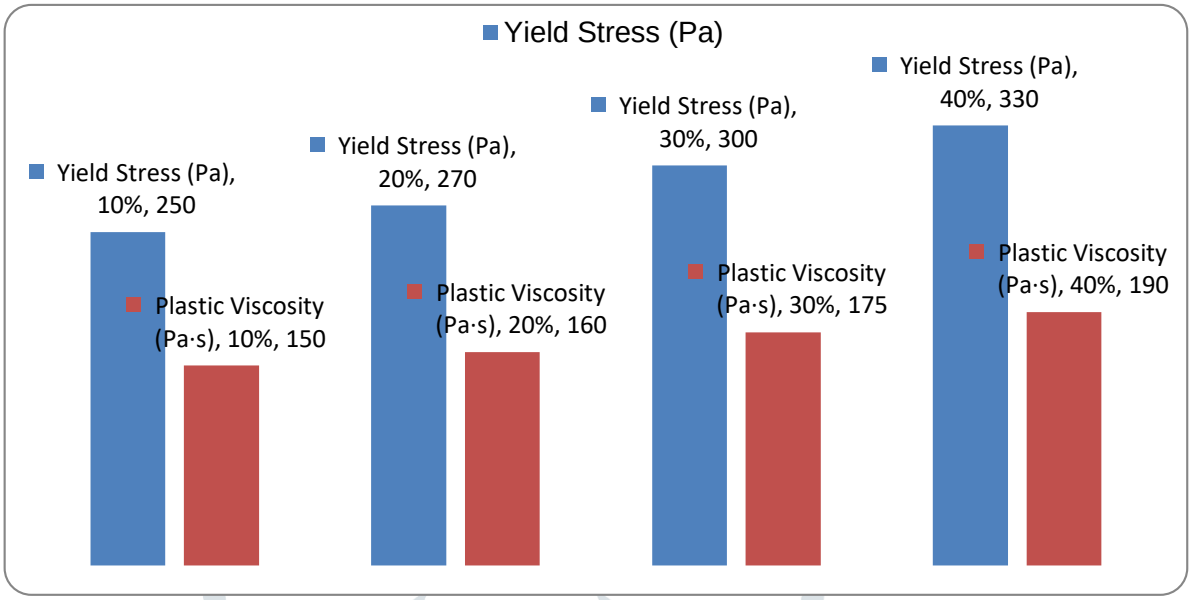
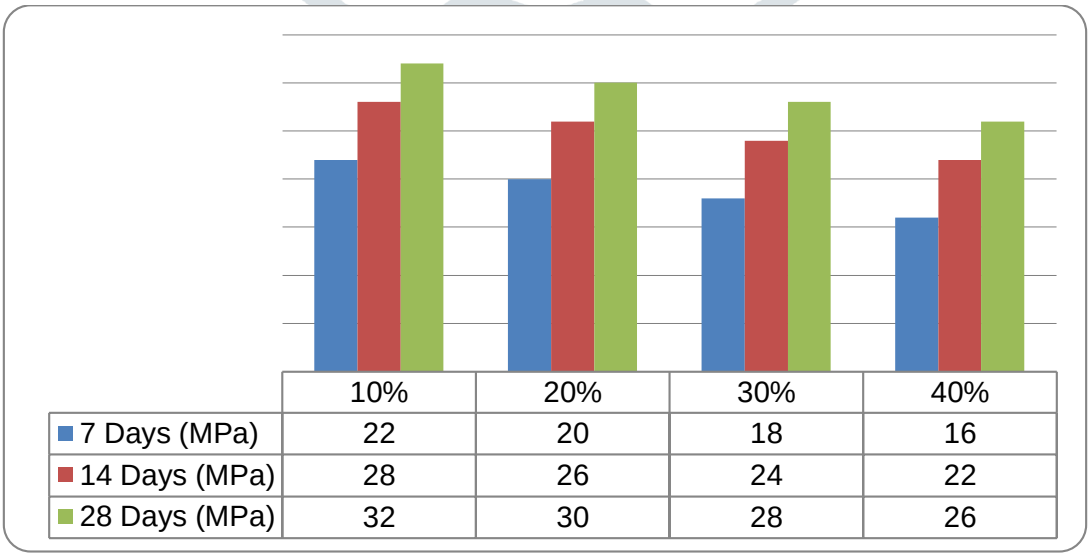



Figure 3. Yield Stress & plastic Viscosity.

➢ **Compressive Strength:** The compressive strength results indicate that up to 20% replacement of cement with spent catalyst, the concrete maintained acceptable strength levels for M20 grade concrete. The addition of the superplasticizer helped in achieving a denser matrix, resulting in improved early-age and long-term strengths. However, at 30% and 40% replacement levels, the compressive strength reduced more noticeably, suggesting that these mixes may require further optimization or supplementary materials to achieve desired strength levels.



| | 10% | 20% | 30% | 40% |
|---|---|---|---|---|
| 7 Days (MPa) | 22 | 20 | 18 | 16 |
| 14 Days (MPa) | 28 | 26 | 24 | 22 |
| 28 Days (MPa) | 32 | 30 | 28 | 26 |

Figure 4. Compressive Strength

- **Flexural Strength:** Similar to compressive strength, the flexural strength showed a decreasing trend with increasing spent catalyst content. The superplasticizer enhanced the flexural strength, particularly noticeable in the 10% and 20% replacement levels. For structural applications requiring high flexural strength, the 30% and 40% replacement mixes may need additional reinforcement or adjustments.

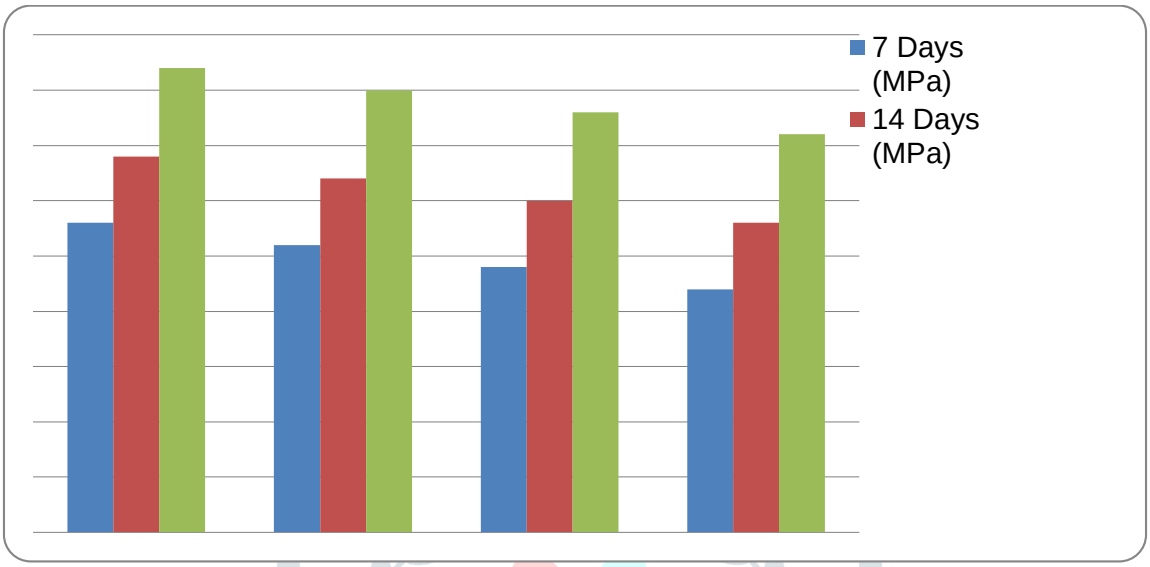



Figure 5. Flexural Strength

## VI. CONCLUSION

1. Spent catalysts have favourable properties, such as significant surface area and pozzolanic activity, beneficial for concrete.
2. Up to 20% cement replacement with spent catalysts is feasible for maintaining acceptable strength and workability in M20 grade concrete.
3. Superplasticizers are crucial in enhancing workability and achieving desired mechanical properties, particularly at higher replacement levels.
4. The addition of superplasticizers maintained acceptable slump flow and workability across various replacement levels.
5. Increased yield stress and plastic viscosity with higher spent catalyst content indicate reduced flow characteristics, necessitating careful optimization.
6. Up to 20% replacement maintained adequate strength for M20 grade concrete, while higher levels (30% and 40%) showed reduced strengths, requiring further mix adjustments.

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