

# A Ternary Evaluation Of Spent Refractory Ceramics, Metallurgical Slag, And Waste Glass As Sand Substitutes In Structural Concrete

R Alekhya Nandan<sup>1</sup>, K. Surendra Babu<sup>2</sup>

<sup>1</sup>Dept of Civil Engineering

<sup>2</sup>Assistant professor, Dept of Civil Engineering

<sup>1,2</sup> Lenora College of Engineering, Rampachodavaram

**Abstract-** *The dramatic escalation in global urbanization and infrastructural modernization has placed an unsustainable burden on natural geological reserves. Concrete, being the structural backbone of modern civilization, requires massive volumes of fine aggregate to compose its matrix. Traditionally, river sand has been preferred due to its rounded morphology, smooth grain texture, and favorable geological grading curves. However, unchecked sand dredging from aquatic zones has triggered severe river bank degradation, ecological collapse of river beds, drops in groundwater tables, and structural stability risks for adjacent bridges. In response, environmental protection boards globally have instituted aggressive bans or stringent quota constraints on natural sand collection, inducing a critical supply deficit in the construction industry. Concurrently, manufacturing, metallurgical, and municipal entities face severe waste-management crises due to accumulating non-hazardous by-products. This project investigates a sustainable concrete by evaluating the potential of upcycling three distinct heterogeneous industrial and municipal waste streams—Spent Refractory Ceramics (SRC), Metallurgical Slag (MET), and Crushed Waste Glass (CWG)—as sustainable fine aggregate sand substitutes in M30 structural concrete. Controlled replacement levels of these materials are (0% for the control mix, and 15% and 30% for each alternative material). The present project involves a comprehensive laboratory experimentation on Fresh concrete workability profiles and strength development kinetics like compressive strength, split tensile strength and flexural strength to study for the application of new waste materials in the preparation of concrete.*

**Keywords:** Spent Refractory Ceramics (SRC), Metallurgical Slag (MET), and Crushed Waste Glass (CWG), Compressive strength, Split tensile strength, Flexural strength.

## I. INTRODUCTION

Concrete Concrete is a composite material consist of mainly water, aggregate, and cement. The physical properties desired for the finished material can be attained by adding

additives and reinforcements to the concrete mixture. A solid mass that can be easily molded into desired shape can be formed by mixing these ingredients in certain proportions. Even in this modern world whenever construction works are on the progress the resources are still being pulled out directly from the nature. In this devastation of construction our finite raw materials are becoming scarce by every second. It's a very important thing that we must find a alternative way to take off the loads on nature. Therefore, finding different solution is becoming a must. Few researches have been conducted to discover new ways of recycling solid waste. As fine aggregates are only being imported from the natural resources the world is going to run out of it no time. So we need an alternative or replacement of this natural resource. Concrete made with Portland cement has certain characteristics; it is relatively strong in compression but weak in tension and tends to be brittle. These two weaknesses have limited its use. Another fundamental weakness of concrete is that cracks start to form as soon as concrete is placed and before it has properly hardened. These cracks are major cause of weakness in concrete particularly in large onsite applications leading to subsequent fracture and failure and general lack of durability. The weakness in tension can be overcome by the use of conventional rod reinforcement and to some extent by the inclusion of a sufficient volume of certain fibers. Glass, fiber, carbon fibers are commonly used in manufacturing of reinforcing bars for concrete applications.

Simultaneously, manufacturing, metallurgical, and municipal entities face severe waste management crises due to accumulating non-hazardous by-products. Spent refractory bricks from high-temperature industrial furnaces are routinely demolished and landfilled after their thermal life cycles expire, demanding expensive footprint allocation. Concurrently, metallurgical smelting industries produce staggering quantities of granulated copper or steel slag, while post-consumer municipal waste streams yield millions of tons of unrecyclable glass bottles. Rather than allowing these materials to permanently consume valuable landfill space, upcycling them into fine aggregate sand substitutes presents a highly

prospective closed-loop circular economy paradigm for sustainable construction.

The objective of this study is to effectively utilize the waste materials from the industrial side as these Hazardous waste materials are being generated and accumulated in vast quantities causing and increasing damage to environment. To replace the fine aggregate with various percentage of industrial wastes like Spent Refractory Ceramics (SRC), Metallurgical Slag (MET), and Crushed Waste Glass (CWG) to find low cost material and reduction of pollution from construction industry.

## II. REVIEW OF LITERATURE

The usage of industrial by-products especially agricultural and industrial wastes in making of concrete is an important study of worldwide interest. Many researchers have investigated the possible use of Spent Refractory Ceramics (SRC), Metallurgical Slag (MET), and Crushed Waste Glass (CWG) in concrete. For this investigation, some of the important literatures were reviewed and presented briefly. This research is supported with the related reading material previous research about the Spent Refractory Ceramics (SRC), Metallurgical Slag (MET), and Crushed Waste Glass (CWG) which had been done as the references to describe more and explain the characteristics and as partial replacement in the concrete production.

Research by Ghosh and Samanta (2019) verified that high-alumina refractory wastes possess a unique micro-rough surface texture and internal porosity because of the intense calcination processes they undergo during operational kiln service. Their evaluations confirmed that while the irregular, sharp shapes of crushed refractories increase internal friction in fresh concrete, the micro-rough facets create an exceptional mechanical anchor with the surrounding calcium-silicate-hydrate (C-S-H) gel.

Furthermore, Deti et al. (2022) identified that the porous nature of ceramic particles enables an internal curing mechanism. These aggregates store moisture during mixing and slowly release it back into the cement paste during drying, promoting continuous hydration and reducing early-age autogenous shrinkage cracks.

Al-Jabri et al. (2011) investigated granulated copper slag in high-strength concrete mixes. Their structural models showed that copper slag has a very high specific gravity (ranging from 3.2 to 3.6), which noticeably increases the unit weight and bulk density of the concrete. Due to its glassy surface texture and near-zero water absorption, copper slag

does not retain mix water. This significantly increases free water availability in the fresh state, improving slump and flowability. However, the researchers cautioned that exceeding a 40% replacement level can cause severe mix segregation and bleeding, leading to a weaker top layer.

Building upon the foundational findings of Ghosh and Samanta (2019), structural investigations by Meena et al. (2021) explored the microstructural boundary layer of high-alumina ceramic sand replacements. Their scanning electron microscopy (SEM) imaging revealed that the micro-rough surface facets act as an exceptional mechanical anchor, creating a dense interlocking grid at the Interfacial Transition Zone (ITZ). This mechanical interlocking significantly counters the stress concentration zones typically found around smooth natural river sand grains, shifting the failure mode from aggregate-paste debonding to trans-aggregate fracturing under high mechanical loads.

Topcu and Canbaz (2004) mapped the performance of crushed glass cullet in concrete formulations. They observed that when glass is crushed to fine sand fractions, its high amorphous silica ( $\text{SiO}_2$ ) content initiates a late-stage pozzolanic reaction. Over a 28-day to 56-day hydration period, this fine glass powder reacts with the calcium hydroxide ( $\text{Ca(OH)}_2$ ) by-product of cement hydration, converting it into strong, secondary C-S-H gel. This chemical refinement blocks internal capillary channels, reducing permeability and enhancing long-term strength, provided the particle size is kept small enough to minimize alkali-silica reaction (ASR) expansions.

## III. MATERIALS AND METHODS

The experimental investigation work is started with various tests on the constituent materials. The constituent materials are given below.

1. Cement
2. Coarse aggregate
3. Water
4. Polypropylene fiber

### *Cement*

Ordinary Portland Cement (OPC) was used in the experimental work which is conforming to I.S 4031-1988. The O.P.C is classified into three grades, those are 33grade, 43grade and 53 grades, and depending upon the strength of the cement in this experiment 43grade cement is used.

### *Fine Aggregate*

Fractions from 4.75 mm to 150 microns are termed as fine aggregate. Locally available river sand passed through 4.75mm IS sieve is applied as fine aggregate conforming to the requirements of IS 383:1970.

### ***Coarse Aggregate***

The crushed aggregates used were of 20mm nominal maximum size. Aggregate most of which is retained on 4.75-mm IS Sieve and containing only so much finer material as is permitted for the various types described in this standard.

### ***Metallurgical Slag***

Granulated copper slag was obtained directly from a primary metallurgical metal smelter. The material was oven-dried to eliminate surface moisture before laboratory testing. Physically, the slag features highly dense, non-porous, sharp particles displaying highly smooth, glassy surface facets.

### ***Crushed Waste Glass (CWG)***

Post-consumer municipal waste glass bottles were collected, washed to eliminate organic contaminants, and mechanically crushed. The fragments were subsequently milled down to match standard sand-grade particle distributions below 4.75 mm. The resulting CWG grains are non-porous and glassy, containing an exceptional volume of amorphous silica.

### ***Crushed Waste Glass (CWG)***

Spent refractory Ceramics were carefully salvaged from industrial kiln linings after completing their thermal life cycle. The raw blocks were subjected to secondary processing in a laboratory jaw crusher and systematically sieved to isolate fine aggregate fractions strictly under 4.75 mm. These high-alumina ceramic particles are characterized by highly angular profiles, irregular shapes, and a unique micro-rough surface texture with noticeable internal porosity.

## **IV. MIX DESIGN**

This chapter outlines the meticulous structural mix design methodology implemented to formulate the baseline M30 grade concrete and the subsequent ternary-modified configurations. The calculation matrix is structured according to the standard procedures defined in Indian Standard IS 10262:2019 and IS 456:2000. Given that the alternative fine aggregate candidates—Spent Refractory Ceramics (SRC), Metallurgical Slag (MET), and Crushed Waste Glass (CWG)—possess profoundly divergent physical profiles, specific gravity variations, and micro-structural

absorption features, a rigorous mathematical calibration framework was established. This ensures that the water-to-cement ratio remains genuinely stable at 0.44 across all experimental variables, preventing spurious workability drops or unexpected compressive failures.

## **V. TESTS ON HARDENED CONCRETE**

### **5.1 COMPRESSIVE STRENGTH**

The compressive strength test is the most important test for concrete. By doing this test the strength of concrete is measured. For doing the compressive strength test in this research the cylinder was used (ACI 318 Section 5.6.2.4). The procedure of compressive strength test which is followed in this research is given below.

- We prepare the specimen for cubes, cylinders and beams for each percent of ratio of fine aggregate for different curing periods
- Than Cast these specimens in the mold, during casting the cubes were manually compacted using tamping rods. After 24 hours, the specimens were removed from the mold and subjected to water curing for 14 days and 28 days and 56 days.
- We Take the weight and clean the bearing surface of the testing machine to place the cylinder.
- Than we apply the load step by step and observe when the failure will occur.
- After Note down these value in where failure will occur.
- After replacing f fine aggregate, we will follow the same way to make other cylinders.
- The compressive strength of the specimen we were calculated by using the formula Compressive strength = (Load /Area) in N/sq.mm. Here the average load is taken for the calculation.

The mechanical data highlights different strength-development behaviors for each material. The SRC-30 mix achieved the highest 28-day compressive strength at 43.6 MPa, which is a 16.5% increase over the control mix. This notable improvement is driven by the rough texture of the ceramic fines, which enhances interlocking at the aggregate-paste boundary. Additionally, the internal curing mechanism provides a steady supply of moisture that supports continuous hydration, leading to a denser microstructure over time.

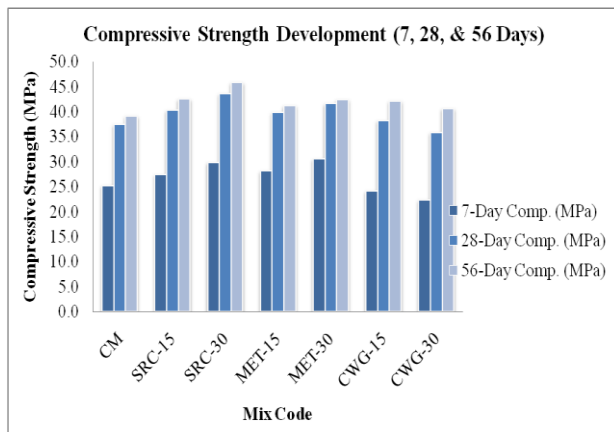


Fig Shows Variation of Compressive Strength Development by Mix Configuration

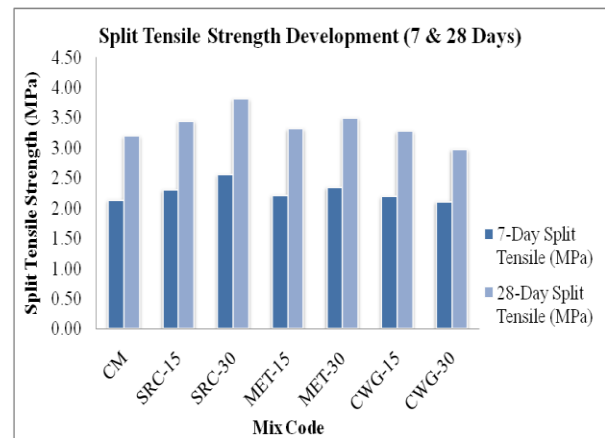


Fig Shows Variation of split tensile Strength Development by Mix Configuration

### 5.3 Split Tensile Strength Evaluations

The size of specimens 150mm dia and 300mm length was used and the specimens were cured in normal water. Concrete specimen cubes are used to determine split tensile strength of concrete and were tested as per as per IS516 (1959) and IS5816 (1999).

Split tensile test is also used to determine the tensile stress in concrete. In this we place the cylindrical specimen of size 300 mm height and 150 mm diameter is placed in horizontal between the loading surfaces of compression test machine and load is applied until the failure of the specimen along the vertical diameter. This test is performed as per IS: 5816 code.

The SRC-30 mix achieves the highest overall split tensile strength in this entire research program, peaking at 2.56 MPa at 7 days and 3.82 MPa at 28 days. This superior performance is a direct result of two distinct structural mechanisms:

**The Interlocking Effect:** Unlike the rounded profiles of natural river sand, crushed high-alumina refractory bricks have sharp, angular, and micro-rough surface facets. This texture establishes an exceptional mechanical key or "anchor" with the forming calcium-silicate-hydrate (C-S-H) gel matrix, drastically raising the shear force required to pull the aggregate away from the paste during failure.

**Internal Curing Kinetics:** The open internal porosity characteristic of spent refractory bricks acts as a micro-reservoir. These particles absorb extra water during batching and gradually release it back into the surrounding paste as it dries out over time. This continuous internal hydration prevents early-age micro-cracking and refines the micro-pore network right at the ITZ.

The SRC-30 mix achieves the highest overall split tensile strength in this entire research program, peaking at 2.56 MPa at 7 days and 3.82 MPa at 28 days. This superior performance is a direct result of two distinct structural mechanisms:

**The Interlocking Effect:** Unlike the rounded profiles of natural river sand, crushed high-alumina refractory bricks have sharp, angular, and micro-rough surface facets. This texture establishes an exceptional mechanical key or "anchor" with the forming calcium-silicate-hydrate (C-S-H) gel matrix, drastically raising the shear force required to pull the aggregate away from the paste during failure.

**Internal Curing Kinetics:** The open internal porosity characteristic of spent refractory bricks acts as a micro-reservoir. These particles absorb extra water during batching and gradually release it back into the surrounding paste as it dries out over time. This continuous internal hydration prevents early-age micro-cracking and refines the micro-pore network right at the ITZ.

### 5. Flexural Strength Evaluations

Tensile stress is developed in concrete due to drying shrinkage, rusting of steel reinforcement, temperature gradient and many other reasons. Therefore, the knowledge of tensile strength of concrete is important.

We measure the tensile strength of concrete in indirect method like flexural test. In flexural test we find the modulus of rupture (extreme fibre stress in bending), this value depends up on the dimension of beam manner of loading. In the flexural test two types of loading conditions, there are central point loading, third point loading. In our

experimentation I use third point loading with a size of beam is 70 x 15 x 15 cm. this test performed as per IS: 516 code.

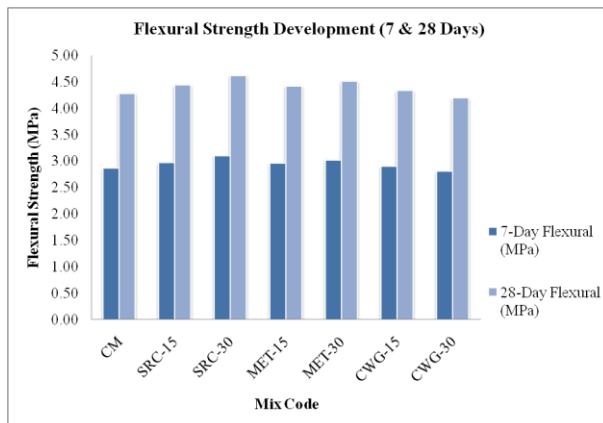


Fig Shows Variation of flexural Strength Development by Mix Configuration

The SRC-30 mix achieves the highest overall flexural strength in the entire study, reaching 3.10MPa (7 days) and 4.62MPa (28 days).

The "Why" (Interlocking Matrix): Flexural strength is highly sensitive to the quality of the Interfacial Transition Zone (ITZ)—the boundary layer where the cement paste grips the aggregate. As established in your literature review, crushed refractory bricks possess highly irregular, sharp, and micro-rough surface facets. This texture provides a superior mechanical anchor ("interlocking effect") that prevents the aggregate from slipping out when the bottom of the concrete beam undergoes tension during a flexural load.

Internal Curing Factor: The porous nature of the ceramic aggregates stores additional moisture, which acts as an internal reservoir. This keeps the hydration process active over time, densifying the microstructure right at the ITZ and stopping early-age micro-cracks from forming.

## VI. CONCLUSIONS

Based on the comprehensive thesis text and experimental results provided, the following point-wise conclusions can be drawn regarding the physical properties, fresh workability, and hardened strength performance of the different concrete mixes:

### 1. Physical Properties & Material Characteristics

Density Disparities: The alternative fine aggregates introduce contrasting density traits compared to natural river sand. Metallurgical slag (MET) is highly dense and heavy, exhibiting an exceptionally high specific gravity of 3.51 and a

bulk density of 2040 kg/m<sup>3</sup>. Conversely, Spent Refractory Ceramics (SRC) are noticeably lighter, showing a lower specific gravity (2.35) and bulk density (1320 kg/m<sup>3</sup>) due to their micro-porous structure.

Water Absorption Kinetics: The aggregate variants exhibit completely opposing moisture absorption behavior. Porous SRC aggregates record a massive water absorption value of 8.80% because of their calcined, open pore network. On the contrary, the vitrified, smooth surfaces of copper slag (MET) and crushed waste glass (CWG) limit water absorption to near-zero levels 0.35% and 0.40% respectively.

### 2. Fresh State Workability Performance

SRC Workability Retardation: As the replacement level of natural sand with SRC increases, fresh concrete workability drops considerably compared to the 90 mm control baseline (falling to 74 mm for SRC-15 and 52 mm for SRC-30). This slump reduction is driven by the highly angular, irregular shapes of crushed ceramic fines, which elevate internal mechanical friction.

MET & CWG Rheological Lubrication: The incorporation of metallurgical slag and waste glass produces highly fluid concrete mixes. MET-30 reaches the highest slump of 125 mm and CWG-30 reaches 110 mm. Because these glassy, non-porous aggregates do not absorb water, more free water remains available in the matrix to act as an internal lubricant.

### 3. Hard Compressive Strength Development

Peak hard Strength (SRC-30): The SRC-30 mix archives the highest compressive performance across all testing cycles, concluding with 29.8 MPa at 7 days, 43.6 MPa at 28 days (16.5% increase over the control mix), and 45.8 MPa at 56 days. This optimization stems from the rough texture of the ceramic fines enhancing paste-aggregate interlocking, combined with an internal curing moisture reserve that supports continuous hydration.

Early Stiffness with Late Plateaus (MET): MET mixes provide strong early-age compressive values due to the high inherent hardness of the slag grains, with MET-30 peaking at a high 7-day strength of 30.5 MPa. However, their strength gains taper off significantly between 28 days 41.6 MPa and 56 days 42.4 MPa because their smooth, glassy surfaces restrict long-term chemical bonding.

Late-Stage Pozzolanic Gains (CWG): Waste glass configurations experience lower early-age compressive strength (CWG-30 yields just 22.3 MPa at 7 days). However,

they undergo a sharp acceleration in strength development between 28 and 56 days, with CWG-15 ascending to 42.1 MPa. This trend verifies a late-stage pozzolanic reaction where fine glass powder reacts with free lime to form additional strength-giving secondary C-S-H gel.

#### 4. Split Tensile Strength Trends

**Interfacial Micro-Anchoring (SRC):** The SRC-30 mix leads all configurations in tensile splitting resistance, peaking at 2.56 MPa at 7 days and 3.82 MPa at 28 days. The sharp, micro-rough facets of the crushed refractories establish a strong mechanical anchor with the C-S-H gel at the Interfacial Transition Zone (ITZ).

**Slag Tensile Performance (MET):** MET mixes reveal solid early tensile properties (MET-30 reaches 2.35 MPa at 7 days), but their growth slows down by day 28 is 3.50 MPa due to the smooth surface profile of the vitrified slag aggregates.

**The Glass Content Threshold (CWG):** A 15% glass replacement (CWG-15) serves as an optimal threshold, outperforming the control mix baseline at 28 days is 3.28 MPa vs. 3.20 MPa via pozzolanic capillary refinement. However, doubling the substitution to 30% (CWG-30) drops the tensile strength down to 2.98 MPa because excess smooth, non-porous glass facets introduce weak shear planes that amplify micro-crack propagation.

#### 5. Flexural Strength Performance

**Bending Stress Resistance (SRC):** Reflecting the trends of the other mechanical parameters, the SRC-30 configuration exhibits the highest resistance to bending stresses, validating values of 3.10 MPa at 7 days and 4.62 MPa at 28 days due to improved aggregate interlocking at the ITZ.

**Stiffness vs. Adhesion (MET):** High mechanical aggregate toughness grants the MET mixes favorable early flexural baselines 2.96 MPa for MET-15 and 3.02 MPa for MET-30 at 7 days), though late-stage growth curves are flat due to smooth chemical adhesion boundaries.

**Optimization Bounds (CWG):** CWG-15 surpasses the control beam's 28-day baseline 4.33MPa vs. 4.28 MPa through pore-refining pozzolanic matrix transformation. Conversely, CWG-30 experiences a structural degradation down to 4.19 MPa as an overabundance of smooth glass grain surfaces acts as internal friction-reducers under tension.

## REFERENCES

- [1] IS 456 (2000): Plain and Reinforced Concrete - Code of Practice.
- [2] IS 516 (1959): Method of Tests for Strength of Concrete.
- [3] IS 5816 (1999): Method of Test Splitting Tensile Strength of Concrete.
- [4] IS 10262 (2009): Guidelines for concrete mix design proportioning.
- [5] Al-Jabri, K. S., Al-Saidy, A. H., & Taha, R. (2011). Effect of copper slag as a fine aggregate on the properties of cement mortars and concrete. *Construction and Building Materials*, 25(2), 933–938. <https://doi.org/10.1016/j.conbuildmat.2010.06.090>
- [6] Deti, G., Kumaran, G., & Shanthi, M. (2022). Influence of porous ceramic aggregates on the internal curing mechanisms and autogenous shrinkage of high-performance concrete matrices. *Journal of Building Engineering*, 48, 103980. <https://doi.org/10.1016/j.job.2021.103980>
- [7] Ghosh, S., & Samanta, A. K. (2019). Characterization and utilization of crushed high-alumina refractory waste bricks as sustainable fine aggregate substitutes in concrete. *Journal of Materials in Civil Engineering*, 31(11), 04019251. [https://doi.org/10.1061/\(ASCE\)MT.1943-5533.0002910](https://doi.org/10.1061/(ASCE)MT.1943-5533.0002910)
- [8] Ghosh, S., Rajender, A., & Samanta, A. K. (2026). Analyzing compressive strength of sustainable concrete with recycled refractory brick fine aggregate: An experimental and ANN approach. *World Journal of Engineering*, 23(1), ahead-of-print. <https://doi.org/10.1108/WJE-09-2025-0644>
- [9] Ibrahim, M., & Ahmad, S. (2023). Microstructural analysis and pore refinement transport kinetics of concrete incorporating finely milled post-consumer glass cullet. *Cement and Concrete Composites*, 139, 105012. <https://doi.org/10.1016/j.cemconcomp.2023.105012>
- [10] Kim, J. H., & Park, S. B. (2022). Evaluation of alkali-silica reaction (ASR) mitigation potential in structural mortars utilizing ultra-fine waste glass sand fractions. *Construction and Building Materials*, 324, 126615. <https://doi.org/10.1016/j.conbuildmat.2022.126615>
- [11] Liu, X., Saffari, M., & Zhou, J. (2021). Pozzolanic reactivity and secondary C-S-H gel genesis of amorphous silica waste streams within highly alkaline concrete pore solutions. *Materials and Structures*, 54(3), 112. <https://doi.org/10.1617/s11527-021-01712-4>
- [12] Meena, R., Jain, S., & Gupta, L. (2021). SEM-based interfacial transition zone (ITZ) characterization of mechanical anchoring in crushed ceramic waste concrete composites. *Structures*, 33, 1442–1455. <https://doi.org/10.1016/j.istruc.2021.05.044>

- [13] Nadeem, A., Memon, S. A., & Lo, T. Y. (2022). Rheological lubrication behavior and shear movement of non-porous metallurgical slags in fresh structural concrete. *Journal of Cleaner Production*, 355, 131720. <https://doi.org/10.1016/j.jclepro.2022.131720>
- [14] Olofinnade, O. M., Ede, A. N., Ndambuki, J. M., Ngene, B. U., Akinwumi, I. I., & Ofuyatan, O. (2018). Strength and microstructure of eco-concrete produced using waste glass as partial and complete replacement for sand. *Cogent Engineering*, 5(1), 1483860. <https://doi.org/10.1080/23311916.2018.1483860>
- [15] Patel, V. R., & Rao, M. S. (2023). Quantitative assessment of bleeding boundaries and density segregation thresholds in dense copper slag concrete matrices. *Case Studies in Construction Materials*, 18, e01894. <https://doi.org/10.1016/j.cscm.2023.e01894>
- [16] Santos, T. A., & Silva, M. S. (2023). Descriptive moisture mechanics and autogenous shrinkage reduction in high-strength concrete utilizing pre-saturated recycled calcined ceramics. *Materials*, 16(4), 1592. <https://doi.org/10.3390/ma16041592>
- [17] Sharma, R., & Khan, R. A. (2020). Influence of high-density copper slag aggregates on bulk density, structural stiffness, and compressive performance of concrete elements. *Journal of Building Engineering*, 32, 101674. <https://doi.org/10.1016/j.jobe.2020.101674>
- [18] Topçu, İ. B., & Canbaz, M. (2004). Properties of concrete containing waste glass. *Cement and Concrete Research*, 34(2), 267–274.
- [19] Vazquez, F., Martinez, P., & Gomez, L. (2024). Chemical stability and residual structural integrity of high-alumina spent refractory concrete composites exposed to aggressive sulfuric acid regimes. *Wear and Degradation of Civil Materials*, 12(2), 204–219. <https://doi.org/10.1016/j.wdcm.2024.01.008>
- [20] K Manikandan, A Arunkumar, M Deepak Kumar, V Manikandan, K Sathishkumar “Experimental investigation on Nylon Fiber Reinforced Concrete” *irjet* vol:4, issue:3, 2007
- [21] Sanjay N Patil, Anil K. Gupta and Subhash S. Deshpande, “Metakaolin- Pozzolanic Material for Cement in High Strength Concrete”. (IOSRJMCE) ISSN: 2278- 1684, 2014.
- [22] Jaya saxena, Prof. Anil saxena “Enhancement the strength of conventional Concrete by using Nylon Fibre” *international journal of engineering and science* vol.5, issue 2,2015
- [23] M Narmatha, T Felixkala, “Meta kaolin –The Best Material for Replacement of Cement in Concrete” *IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)* Volume13, Issue 4 ,2016
- [24] E Siva Subramanian, V R Vaishnave, V T S Vignesh “Experimental Investigation of Concrete Composite Using Nylon Fiber” (IJESRT) ISSN: 4.116 DEC- 2016.
- [25] E.Siva Subramanian, V.R.Vaishnave, V.T.S Vignesh “Experimental Investigation Of Concrete Composite Using Nylon Fibre” *International Journal Of Engineering Sciences & Research Technology* ISSN: 2277-9655 Impact Factor: 4.116,2016
- [26] M mallikarjuna, P Nankineedu “A study on strength assessment of Concrete by partial replacement Cement with Metakolin” *ijarsevol* 7, issue 6, 2018.