A Multifaceted Study on Mechanical Strength, Workability and Microstructural Analysis of Zeolite Enhanced Concrete

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Abstract - *The present work offers a thorough exploration of the mechanical and workability features of concrete, accompanied by a meticulous analysis of the microstructural attributes of Zeolite as a novel addition. The research involves a comprehensive experimental programme aimed at investigating the impacts of different concentrations of Zeolite on the compressive strength, flexural strength, and durability properties of concrete. Concurrently, sophisticated microscopy and spectroscopic methods are used to examine the morphological and crystallographic characteristics of Zeolite particles and their interactions inside the cementitious matrix. The results of this study provide valuable insights into the intricate relationship between Zeolite and the components of concrete, therefore expanding our knowledge of the material's capacity for improved performance and environmentally friendly building methods.*

Key Words: Natural Zeolite, Microstructural Studies, Compression, Flexure, Split Tensile, Workability

1. INTRODUCTION

There is a requirement to investigate sustainability within the realm of civil construction.[1] Introducing zeolite concrete, an innovative and environmentally conscious construction material that has garnered increasing attention in recent years. Zeolite concrete is distinguished by the incorporation of zeolites, naturally occurring minerals with remarkable adsorption and ion-exchange properties, into the traditional concrete mixture. Zeolite has a substantial capacity to significantly improve various engineering aspects, including but not limited to shrinkage, chloride infiltration, permeability to water, resistance to carbonation, and resistance to sulfates.[2] This unique integration not only enhances the material's mechanical and durability characteristics but also offers a promising avenue for addressing sustainability challenges in the construction industry.

2. OBJECTIVES

- To establish a suitable ratio of natural zeolite to use in place of cement in concrete mixes so as to achieve the desired positive effects.
- To discover the qualities of the concrete that affect its workability.

3. LITERATURE REVIEW

Babak Ahmadi, Mohammad Shekarchi (2009) conducted a study with the objective of investigating and analysing multiple facets pertaining to the selected topic. This research paper seeks to evaluate the effectiveness of incorporating locally sourced natural zeolite as a pozzolanic material in enhancing the mechanical and durability properties of concrete. The study will employ a thorough examination of pertinent scholarly articles and empirical evidence to achieve its objectives. The present study aims to examine and analyse the pozzolanic reactivity of natural zeolite and silica fume. By conducting a comprehensive investigation, this research seeks to contribute to the existing body of knowledge on the subject matter. The pozzolanic reactivity of these two materials will be carefully assessed and compared, shedding light on their potential applications in various industries. Through rigorous experimentation and analysis, this study aims to provide valuable insights into the reactivity of natural zeolite and silica fume, thereby enhancing our understanding of their potential The findings of this study suggest that natural zeolite demonstrates a notable degree of reactivity, although it is comparatively lower when compared to silica fume. The present study aimed to conduct an experimental investigation on concrete mixtures containing different proportions of zeolite and silica fume. The findings of the investigation demonstrated that the incorporation of zeolite into the composition of the concrete mixture resulted in improved performance attributes. The user has provided a numerical reference without any accompanying text. This lack of context makes it difficult to ascertain the specific topic or purpose of the reference. In order to provide a comprehensive analysis, it is necessary to have additional information or context regarding the numerical reference. [4]

Malek Mohammad Ranjbar et al (2013) The purpose of this research was aimed to evaluate the effects of incorporating natural zeolite (NZ) on the properties of fresh and hardened self-compacted concrete (SCC). In this study, a series of self-consolidating concrete (SCC) blends were formulated by introducing varying proportions of nanozeolite (NZ) into the cement matrix. The NZ content ranged from 0% to 20% of the total weight of cement. Additionally, different water-to-binder ratios were employed in order to investigate their influence on the properties of the SCC blends. The results of the study revealed that the introduction of NZ resulted in improvements in the flowability of SCC, its ability to navigate through narrow gaps, and its overall viscosity. These enhancements collectively contributed to the satisfactory performance of the material. However, as the duration of transportation increased, there was a noticeable decline in the flowability of the concrete, particularly when higher amounts of NZ (New Zealand) were present. The inclusion of New Zealand (NZ) in the composition of self-compacting concrete (SCC) mixtures has been observed to yield predominantly positive effects on both the compressive and splitting tensile strengths. The aforementioned impact was found to be more pronounced in concrete mixes that exhibited both higher slump flow and extended mixing durations. In terms of its absorption properties, it was observed that the addition of NZ to SCC resulted in a significant reduction in absorption over time, especially when compared to conventional SCC samples. [5]

Barbara Belen Raggiotti et al (2018) The present study offers a comprehensive overview of the achievement of durability attributes, which were generally found to be satisfactory. The present study investigates the efficacy of zeolite application in combination with conventional Portland cement to determine the optimal conditions for achieving maximum effectiveness. The mechanical properties of concrete demonstrate a prolonged resistance, surpassing the 28-day period. [6]

4. MATERIAL USED

4.1 CEMENT: This study focuses on the analysis of Ordinary Portland Cement (OPC) of grade 53, which adheres to the specifications outlined in the Indian Standard (IS) 12269. OPC is a widely used construction material due to its desirable properties and versatility. The grade 53 designation indicates that the cement possesses a higher compressive strength compared to lower grade variants. The adherence to IS 12269 ensures that the cement meets the prescribed quality standards and can be reliably utilised The present study aimed to ascertain the characteristics of cement through the implementation of a standardised operating method. The aforementioned characteristics are presented in the following table. The primary fundamental characteristics that were determined in this study include early consistency, normal specific gravity, and final setting time. These parameters were investigated to gain insights into the properties of the material under investigation.

Table -1: Properties of Cement.

Properties	Cement
Specific Gravity	3.15
Fineness	5.6%
Standard Consistency	30%
Initial Setting Time	36 min
Final Setting Time	480 min

4.2 FINE AGGREGATE: The modulus of fineness of sand typically falls within the range of 2.6. The aforementioned evidence suggests that the sand particles carry a relatively small size and are rightly graded, exhibiting a diverse range of sizes that enhances the workability and strength of concrete blends.

4.3 COARSE AGGREGATE: In the context of concrete and aggregates in India, it is pertinent to note that the Indian Standards (IS) has established a comprehensive set of guidelines and regulations to ensure the quality and safety of these materials. Among these standards, IS 383 holds particular significance. IS 383, titled "Specifications for Coarse and Fine Aggregates from Natural Sources for Concrete," serves as the applicable IS code for concrete and aggregates in India. This code outlines the specifications and requirements that must be met by the coarse and fine aggregates used in the production of concrete. By adhering to the The present document bears the title "Specification for Coarse and Fine Aggregates from Natural Sources for Concrete." The utilisation of 20 mm coarse aggregate in various construction applications, particularly in reinforced concrete structures like columns, beams, slabs and foundations, is a common practise as per the guidelines outlined in IS 383. Therefore, a diameter of 20mm has been selected as the optimal parameter for the purposes of this research investigation.

4.4 SUPER PLASTICIZER: The present study focuses on the characterization and properties of CONPLAST SP430, a chloride-free super plasticizing admixture. This research paper aims to provide a comprehensive analysis of the aforementioned admixture, specifically its physical and chemical properties, as well as its behaviour when dispersed in water. CONPLAST SP430 is a brown solution that exhibits rapid dispersibility in water. It is widely used in various construction applications due to its super plasticizing properties. The absence of chloride in its composition makes it an environmentally friendly choice, as chloride-based admixtures can have detrimental effects on reinforced concrete structures. The physical properties of CONPLAST SP430 play a crucial role in its effectiveness as a super plasticizing admixture. Its brown coloration is a distinctive characteristic, allowing for easy identification and differentiation from other admixtures. Furthermore, its high solubility in water enables quick and efficient dispersion, facilitating its The material in question exhibits remarkable levels of durability and strength during its initial stages of development. The reduction of water required for concrete mixing has been a subject of significant interest and research in recent years. This approach aims to achieve a substantial decrease in the amount of water used during the concrete mixing process. The purpose of this paper is to explore the potential benefits and implications of this practise, as well as to examine the various methods and technologies that have been developed to achieve this objective. By significantly reducing the water content in co In the present scenario, it can be observed that CONPLAST exhibits suitability for application in precast concrete structures as well as other situations that require the attainment of high early strength. The present study aims to investigate the potential of enhancing the efficacy of precast and site-mixed concrete while maintaining a sustainable water consumption level. By exploring various methods and techniques, this research seeks to identify strategies that can optimise the performance of concrete without exacerbating water requirements. The delivery of enhanced durability in concrete structures is achieved through the implementation of techniques that effectively raise the final strengths and reduce the permeability of the material. The utilisation of this technology facilitates substantial reductions in the water-to-cement ratio, thereby enabling the production of high-strength concrete with a reduced cement content.

4.5 WATER: The utilisation of uncontaminated portable water, devoid of acidic elements and organic substances, for the purpose of concrete mixing and curing, is a practise that offers significant benefits without incurring any additional costs.

4.6 NATURAL ZEOLITE: Zeolite, a naturally occurring mineral, has garnered significant attention as a promising cementitious material in the field of sustainable construction. With its unique properties and characteristics, zeolite exhibits the potential to revolutionise the construction industry by offering a more environmentally friendly alternative to traditional cementitious materials. This paper aims to explore the various applications and benefits of utilising zeolite in sustainable construction practices. One The utilisation of zeolite as a supplementary cementitious material is attributed to its high content of reactive $SiO2$ and $Al2O3$, which enables it to chemically react with $Ca\ (OH)\ 2$ generated during cement hydration. This reaction results in the formation of additional aluminates and C-S-H gel[3], thereby enhancing the overall performance of the cementitious system. In this study, we aim to investigate the effects of a specific intervention on a particular outcome. The purpose The present study aims to investigate the microstructural characteristics of zeolite powder through the utilisation of scanning electron microscopy (SEM) analysis. The obtained results reveal the presence of irregularly shaped crystals, exhibiting a rough texture. Furthermore, the surface morphology of the zeolite powder exhibits visible pore openings. The present study investigates the distribution of particle size, revealing a heterogeneous distribution characterised by a wide range of particle sizes. The observed distribution encompasses both smaller individual particles and larger particles. The observed structure exhibits characteristics of crystalline formations, displaying a notable level of porosity. Visual examination reveals the presence of visible cracks, as well as void spaces within the material. No signs of contamination are detected upon inspection. Figure 1 displays the scanning electron microscope (SEM) image of the natural zeolite powder.

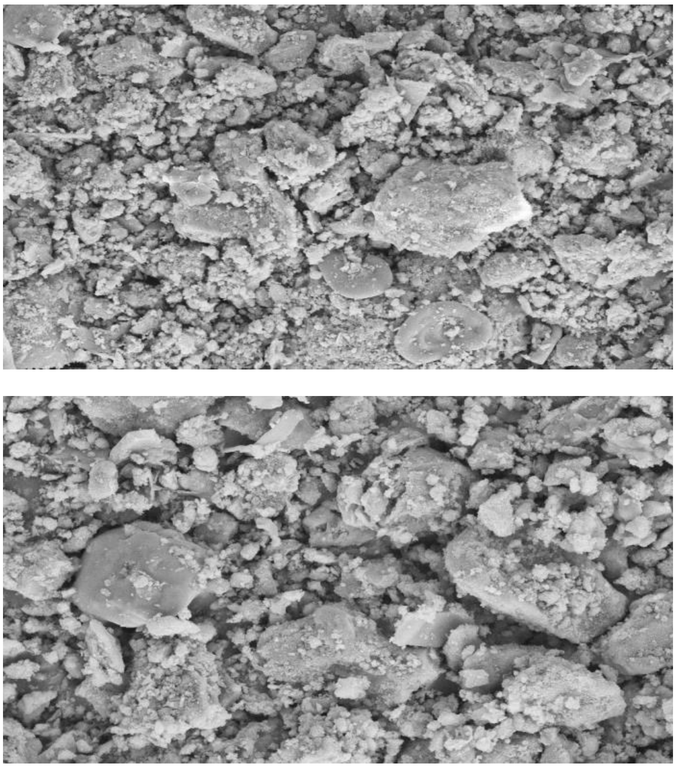

Fig. 1: SEM Image of the Natural Zeolite Powder

The utilisation of the Scanning Electron Microscope (SEM) has enabled researchers to obtain high-resolution images of natural zeolite powder, thereby providing valuable insights into its intricate and fine structure at the microscopic level. The surface and particles of the zeolite exhibit a distinct texture and porosity, which suggests a substantial surface area and the possibility of engaging with various substances, including cementitious materials found in concrete.

In this study, we present Table 2, which offers a comprehensive overview of the chemical properties of the zeolite powder acquired from the manufacturer. The table presents a detailed analysis of various chemical characteristics associated with the zeolite powder, providing valuable insights into its composition and properties. This information is crucial for understanding the potential applications and performance of the zeolite powder in various fields. The comprehensive nature of Table 2 ensures that researchers and practitioners can make informed decisions regarding the utilisation of this zeolite powder in their respective domains. The properties of zeolite provide valuable insights into its composition and potential behaviour when used as an additive in concrete production.

Silicon dioxide ($SiO2$), commonly known as silica, is a prominent constituent of zeolites, accounting for approximately 52% of their composition. Its significant presence in zeolites underscores its importance in understanding the properties and behavior of these materials. The contribution of zeolite particles to the overall structure and stability is a significant aspect that has been extensively studied in the field of materials science. Zeolites are crystalline aluminosilicate minerals with a porous structure, which makes them highly attractive for various applications such as catalysis, adsorption, and ion exchange. The structural integrity and stability of zeolite particles play a crucial role in determining their performance and durability in these application

Aluminium oxide (Al2O3) is a compound that plays a noteworthy role, constituting approximately 46% of the composition. The analysis indicates that the zeolite exhibits a notable abundance of aluminium, a characteristic that may have significant ramifications for its reactivity and its interactions with various constituents within concrete.

Iron oxide, also known as Fe2O3, is a compound that is found in zeolite particles at a relatively low concentration of 0.6%. This presence of iron oxide in zeolite particles may potentially play a role in their coloration. Based on the available evidence, it is improbable that the given concentration will have a substantial effect on the properties of concrete.

Titanium dioxide (TiO2) is a compound that is present in the zeolite at a concentration of 0.65%. Although this proportion is relatively small, it is worth considering its potential impact on the overall properties of the zeolite.

Calcium oxide (CaO), also known as quicklime, is a chemical compound that may have a potential impact on the reactivity of zeolite when exposed to water and during the hydration process of concrete. The presence of calcium oxide in zeolite, with a concentration of 0.09%, suggests that it could potentially influence the aforementioned reactions. Further investigation is required to fully understand the extent of calcium oxide's influence on the reactivity of zeolite and its role in the hydration process of concrete.

The compound magnesium oxide (MgO) is found in trace amounts of 0.03% in the zeolite or concrete samples under investigation. Consequently, its presence is considered minimal and is expected to have limited impact on the properties of these materials.

Sodium oxide (Na2O) and potassium oxide (K2O) are two alkali oxides that are found in relatively small amounts, comprising approximately 0.1% and 0.03% of the total composition, respectively. The potential influence of additives on the behaviour of zeolites in terms of reactivity and interaction with other components in the concrete mix has been a subject of interest in recent research.

The amalgamation of these chemical properties establishes a fundamental basis for comprehending the potential interactions between zeolite, cementitious materials, and water within the context of a concrete mixture. The presence of a substantial quantity of silica and aluminium, as evidenced by the SEM image displaying a porous structure, indicates that the zeolite possesses characteristics that have the potential to enhance the strength, durability, and workability of concrete, provided it is utilised in a careful and deliberate manner within the concrete mixture.

Table -2: Chemical Properties of zeolite from the manufacturer.

Compound	Percentage (%)
SiO^2	52
Al^2O^3	46
Fe^2O^3	0.6
TiO^2	0.65
CaO	0.09
MgO	0.03
Na_2O	0.1
K^2O	0.03

5. MIX PROPORTIONS

Table -3: Mix Proportions of the concrete as per IS 10262:2019

Cement	367.43 kg/m^3
Fine Aggregate	779 kg/m^3
Coarse Aggregate	1384.82 kg/m^3
Water	161.67 kg/m^3
Water Cement Ratio	0.43

Mix Ratio: 1: 2.1: 3.77

The table provides comprehensive mix proportions for concrete in accordance with the IS 10262:2019 standard. For each cubic meter of concrete, it specifies the inclusion of 367.43 kg of cement, 779 kg of fine aggregate, 1384.82 kg of coarse aggregate, and 161.67 kg of water. The water-cement ratio, a critical factor affecting the mix's workability and strength, is set at 0.43. The mix ratio of 1:2.1:3.77 signifies the relative composition of cement, fine aggregate, and coarse aggregate. These proportions and ratios are designed to ensure a balanced combination that achieves the desired strength, durability, and workability of the concrete. By following the IS 10262:2019 guidelines, engineers and construction professionals can create consistent and high-quality concrete mixes suitable for various applications. The specified quantities and ratios play a crucial role in optimizing the performance of the concrete while maintaining the structural integrity and performance requirements of the constructed elements.

6. COMBINATIONS OF SPECIMEN

Table -4: Different combinations of Zeolite Concrete

MIX	COMPOSITION	CEMENT	ZEOLITE
CON 30	Conventional concrete	100	0
NZ 5	Cement + 5% Natural Zeolite	95	5
NZ 10	Cement + 10% Natural Zeolite	90	10
NZ 15	Cement + 15% Natural Zeolite	85	15

7. TESTING OF SPECIMEN

7.1 SLUMP CONE TEST

The objective of this study was to assess the workability of fresh concrete through the implementation of the slump cone test, following the prescribed procedures specified in the IS Code 1199-1959. The analysis of the results obtained from the slump cone test reveals a clear trend indicating a decrease in the slump value of the concrete as the proportion of natural zeolite in the concrete mixture increases. This research paper aims to present the results obtained from the slump cone test, as illustrated in Chart No. 1. The obtained test results offer significant insights into the behaviour and characteristics exhibited by the material under investigation.

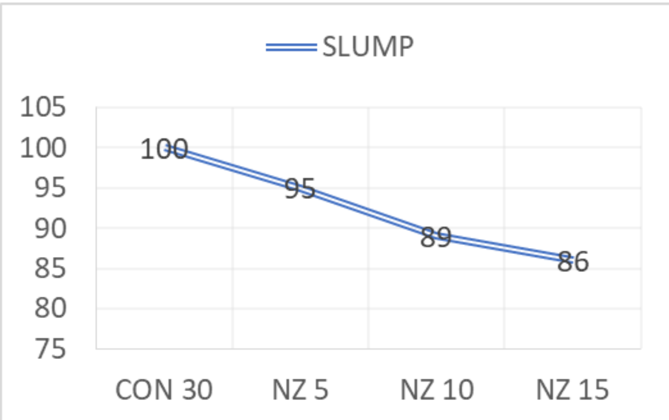

Chart – 1: Slump Properties

7.2 COMPACTION FACTOR TEST

The goal of the compaction factor test, which evaluates the workability of newly mixed concrete and is carried out in accordance with the requirements provided in the Indian Standard IS: 1159 – 1959, is to determine how well freshly mixed concrete can be compacted. It is possible to calculate the concrete mixture's compaction factor by making use of the method that is outlined in the standard. Notably, the addition of natural zeolite to the mixture of cementitious materials used in the manufacturing of concrete has resulted in a considerable decrease in the compaction factor. This is an important development. The use of natural zeolite as an extra cementitious component has been a significant contributor to the success of this endeavour. In this particular setting, the water-absorption capability of the natural zeolite powder is an extremely significant factor to take into account, and it is imperative that this aspect be emphasised. Chart No. 2 provides a graphical representation of the percentage of the concrete mixture that can be compacted successfully with the laboratory procedure.

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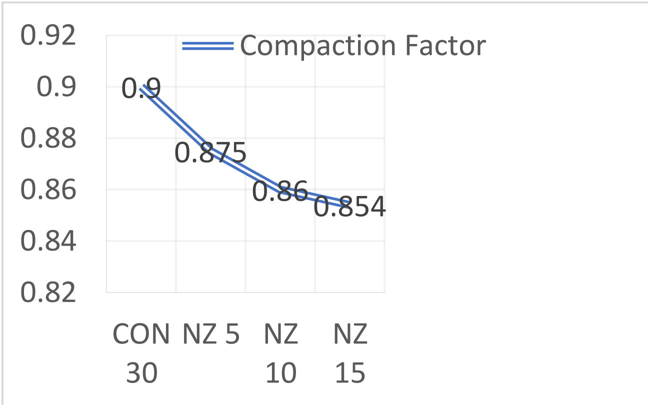

Chart – 2: Compaction Properties

7.3 COMPRESSIVE STRENGTH TEST

The Indian Standard 516 (1959) states 150mm x 150mm x 150mm cubes are employed to test the compression strength. This was done with a servo-controlled Universal Testing Machine (UTM) that could hold up to 3000kN. The cube sample was tested over the course of 7, 14, and 28 days. In this study work, we show how Chart 3 shows the compressive strength features of concrete examples. The chart shows how the data obtained and analysed for the purpose of the research were put together. Figure 2 shows how concrete is crushed during a test of its compression capacity. By looking at how concrete changes during a compressive strength test, you can learn a lot about the material's ability to fight horizontal loads and keep its shape when compressed. When compared to other samples, the compression strength of the (NZ) 10 example shows a clear rise. This suggests that the quality of the concrete and the way it was mixed is better.

Fig-2: compressive strength test (N/mm²)

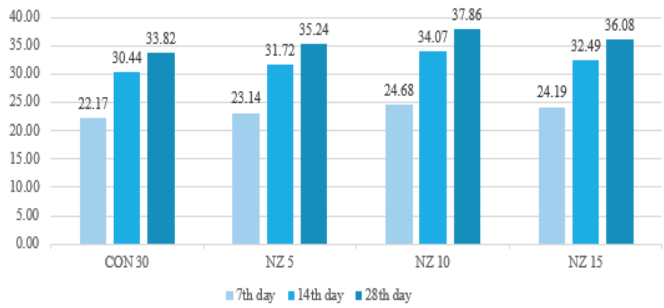

Chart – 3: Compressive strength of the concrete (N/mm²)

7.4 SPLIT TENSILE STRENGTH TEST

The assessment of split tensile strength involved the utilization of cylindrical specimens measuring 300mm in height and 150mm in diameter. This adhered to the guidelines outlined in IS 516 (1959), employing a servo-controlled Universal Testing Machine (UTM) with a capacity of 3000kN. The cylindrical specimens underwent testing at both 14 and 28 days to ascertain strength development over time. Chart - 4 graphically represents the split tensile strength properties of the concrete specimens. Notably, the data demonstrates an optimal strength enhancement of 5.2% with the introduction of 10% zeolite into the mix. In contrast, a decline in split tensile strength was observed with a 15% zeolite content. Figure - 3 provides a visual representation of how the addition of different percentages of zeolite impacts the concrete's split tensile strength, highlighting the notable increase at the 10% zeolite inclusion level and the subsequent decrease at 15%. The results underscore the significance of selecting appropriate zeolite proportions to optimize concrete strength, ensuring the durability and performance of the material in various construction applications.

Fig-3 Split Tensile Strength

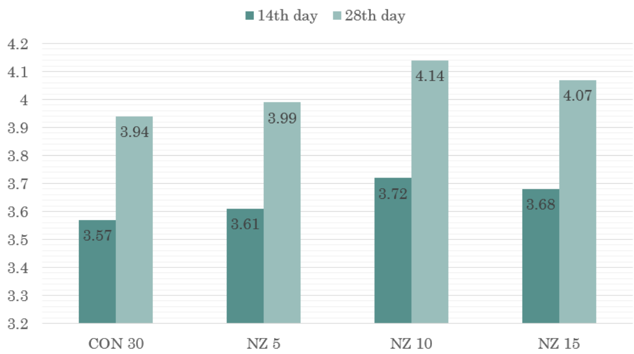

Chart – 3: Split tensile strength of the concrete (N/mm²)

7.5 FLEXURAL STRENGTH TEST

The evaluation of flexural strength involved the use of prismatic specimens measuring 100mm x 100mm x 500mm, adhering to the guidelines stipulated in IS 516 (1959). The tests were conducted at the 28-day mark, employing the 2-point loading method with a distance of 133mm between the two roller point loads. Chart - 5 graphically represents the flexural strength properties of the concrete specimens. It is evident that the specimens experienced failure under flexural loading conditions. Notably, the data portrays a significant enhancement in flexural strength when incorporating 10% zeolite into the mix. This composition yielded a remarkable flexural strength of 4.21 N/mm². Figure - 4, visually illustrates the manner in which the concrete specimens failed during the flexural strength tests. This provides a clear representation of the structural behaviour and failure mechanisms exhibited by the concrete under flexural loading conditions. This experimental exploration underscores the impact of zeolite inclusion on the flexural strength of the concrete specimens. The findings highlight the potential benefits of incorporating zeolite, particularly at a 10% proportion, in enhancing the flexural performance of the concrete.

Fig.4 Flexural Strength of concrete

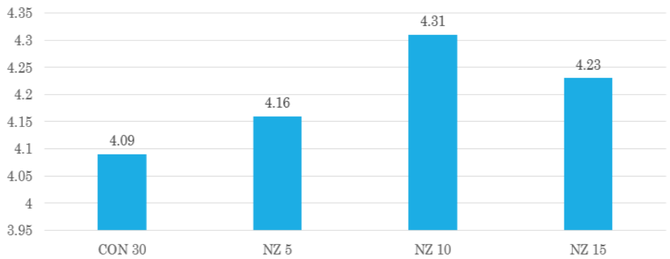

Chart – 5: Flexural strength of the concrete (N/mm^2)

8 CONCLUSIONS

- Zeolite functions as a pozzolanic material, enhancing concrete strength through a chemical reaction with calcium hydroxide during the hydration process. This interaction generates supplementary cementitious compounds, which in turn elevate the binding properties and compactness within the concrete matrix.

- Despite the incorporation of plasticizer CONPLAST SP 430, the mitigating effect on decreased concrete workability caused by the strong water-absorption tendency of natural zeolite powder is limited. The plasticizer fails to fully counteract the impact of zeolite's water-absorbing characteristics on concrete's ease of manipulation.

- The introduction of 10% natural zeolite powder as a substitute for cement yields a gradual and noticeable enhancement in compressive, split tensile, and flexural strengths of the concrete. This strategic addition of zeolite contributes positively to the overall mechanical performance of the concrete mixture.

- The pinnacle of compressive strength reached an impressive 37.86 N/mm^2, showcasing a substantial 11.9% improvement over the strength exhibited by the conventional mix. This substantial gain in compressive strength is a direct result of the zeolite addition's favorable impact on the concrete's structural properties.

- Specifically in the NZ-10 specimen, the zenith of compressive strength attainment is marked at 37.86 N/mm^2. This achievement not only demonstrates the potency of zeolite but also underscores an impressive 11.9% surge when contrasted with the strength of the conventional mix.

- The highest point of split tensile strength, registering at 3.56 N/mm^2 in the NZ-10 specimen, reveals a noteworthy 5.2% advancement in comparison to the split tensile strength exhibited by the conventional mix. This enhancement emphasizes the positive role of zeolite in improving the material's tensile properties.

- Notably, the NZ-10 specimen stands out by displaying the most robust flexural strength of 4.21 N/mm^2. This achievement signifies a commendable 6.7% increase over the flexural strength observed in conventional concrete. The incorporation of zeolite, particularly at the 10% proportion, evidently contributes to the material's flexural prowess.

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