International Journal of Emerging Research in Engineering, Science, and Management
Vol. 3, Issue 4, pp.11-19, Oct-Dec 2024.
www.ijeresm.com eISSN – 2583-4894

Impact of Ceramic Insulator Waste as Partial Replacement of Coarse Aggregate in Concrete: An Experimental Study and Evaluation of Mechanical Properties

[1]Seelam Rajesh, [2]K. Sai Anitha, [3]Ch. Sivanarayana

[1]P.G. Scholar, Department of Civil Engineering, Bonam Venkata Chalamayya Engineering College (Autonomous), Odalarevu, Andhra Pradesh, India. rajeshseelam054@gmail.com
[2]Assistant Professor, Department of Civil Engineering, Bonam Venkata Chalamayya Engineering College (Autonomous), Odalarevu, Andhra Pradesh, India. anithakajuluri@gmail.com
[3]Associate Professor, Department of Civil Engineering, Bonam Venkata Chalamayya Engineering College (Autonomous), Odalarevu, Andhra Pradesh, India. sivanarayanachinta@gmail.com

Abstract: This study investigates the use of ceramic insulator waste (CIW) as a partial replacement for coarse aggregate in concrete, along with the effects of curing conditions on the mechanical properties of the resulting concrete mixtures. Concrete specimens with varying percentages of CIW replacement (0%, 2%, 4%, 6%, 8%, and 10%) were subjected to compressive strength, flexural strength, and tensile strength tests at 7 days, 14 days, and 28 days. Additionally, the specimens were cured under both traditional water curing and acidic curing conditions to assess the impact of different curing environments on concrete performance. The results indicate a consistent increase in compressive strength, flexural strength, and tensile strength of concrete with increasing CIW replacement by up to 4%, regardless of the curing method. However, beyond the 4% replacement threshold, there is a slight decline in mechanical properties. Furthermore, the study highlights the necessity of optimizing mix proportions and implementing quality control measures to mitigate the negative effects of higher CIW replacement ratios. These steps are essential to ensure the durability and structural integrity of concrete structures. This research contributes to the growing body of knowledge on sustainable construction materials and provides valuable insights for engineers and researchers aiming to develop environmentally friendly and structurally sound concrete mixtures.

Keywords: Ceramic Insulator Waste, Concrete, Environmental benefits, Mechanical properties, Structural integrity, Sustainable construction.

1 INTRODUCTION

The construction industry plays a pivotal role in global economic development, with concrete being the most widely used material in both Indian and global contexts. However, conventional concrete production depletes significant natural resources and energy, contributing to environmental degradation and carbon emissions. Hence, sustainable alternatives are crucial to mitigate these impacts without compromising performance.

1.1 Construction Industry in Andhra Pradesh

In Andhra Pradesh, a rapidly developing state in southern India, the construction sector is experiencing rapid growth due to numerous infrastructure projects such as highways, bridges, and urban developments. The rising population and urbanization drive the demand for construction materials, but this growth also presents challenges like resource depletion and waste generation. Sustainable practices and materials are essential for the long-term viability of Andhra Pradesh's construction industry. In India, the construction sector contributes approximately 8% to the Gross Domestic Product (GDP) and employs over 40 million people directly and indirectly (National Skill Development Corporation, 2020). With rapid urbanization and large-scale infrastructure projects, the demand for concrete is set to rise. However, traditional concrete production methods present significant environmental challenges, including resource depletion, greenhouse gas emissions, and construction waste generation.

Globally, the construction industry is shifting towards sustainability due to regulatory frameworks, market demand for green buildings, and increased environmental awareness. According to the United Nations Environment Programme (UNEP), the construction sector is responsible for about 38% of global energy-related CO_2 emissions and consumes around 50% of global resources. Therefore, the adoption of sustainable construction practices and materials is imperative to reduce the environmental footprint.

One promising approach involves using industrial by-products or waste materials as supplementary cementitious materials or aggregates. CIW, a by-product of the ceramic industry, offers potential due to its abundance and suitable physical properties for concrete production. In India, the ceramic industry plays a significant economic role, particularly in regions like Gujarat, Rajasthan, Uttar Pradesh, and Tamil Nadu.

1.2 Ceramic Insulator Waste

Ceramic Insulator Waste is derived from discarded electrical insulators used in power transmission and distribution systems. These insulators, made from ceramic materials, are replaced periodically due to damage or technological advancements. Instead of disposal in landfills, CIW can be repurposed as an aggregate in concrete, offering environmental and resource conservation benefits. In Andhra Pradesh, where rapid industrialization and urbanization drive the demand for construction materials, the use of CIW presents a sustainable solution to both environmental and economic challenges. The incorporation of CIW in concrete offers multiple environmental and economic advantages. It reduces the demand for natural aggregates, conserving resources and minimizing quarrying activities, which often result in habitat destruction and landscape alteration. Additionally, using CIW diverts waste from landfills, aligning with waste management strategies. CIW can also enhance concrete properties such as durability, shrinkage resistance, and thermal insulation, contributing to high-performance and sustainable construction materials.

Several studies have investigated the feasibility and effectiveness of using CIW in concrete mixtures. These studies have focused on mix design optimization, mechanical properties, durability, and environmental impact. While challenges such as potential alkali-silica reaction (ASR) and variability in CIW properties exist, ongoing research aims to overcome these issues and enhance the applicability of CIW-based concrete. In line with global sustainability initiatives and India's commitment to achieving its Sustainable Development Goals (SDGs), the adoption of CIW-based concrete represents a significant step toward greener construction practices. By promoting resource efficiency, waste valorization, and the principles of the circular economy, the use of CIW contributes to the transition to a sustainable construction industry.

2 LITERATURE SURVEY

The use of recycled aggregate in concrete production has been the focus of many studies, driven by environmental concerns and sustainability. Xiao et al. [1] explored the mechanical properties of recycled aggregate concrete (RAC) under uniaxial loading, providing insights into how varying percentages of recycled coarse aggregate (RCA) impact compressive strength and stress-strain behaviour. Ajdukiewicz and Kliszczewicz [2] extended this research, focusing on the properties of concrete with recycled aggregates and their structural behaviour under loading. Behera et al. [3] addressed the sustainability challenges in construction, emphasizing the environmental benefits of utilizing recycled aggregates.

Bommisetty et al. [4] examined the potential of waste ceramic tiles as a partial replacement for natural aggregates, finding that a 20% substitution provided optimal results in terms of strength improvement. Tayeh et al. [5] highlighted the potential of recycled aggregate in high-performance concrete (HPC), examining the mechanical properties and durability. The findings suggest that recycled aggregates can positively affect compressive strength but may reduce workability due to their porous nature. Amin et al. [6] investigated the use of nano cotton stalk ash (NCSA) and palm leaf ash (PLA) as partial replacements for cement in ultra-high-performance concrete (UHPC), showing significant improvements in compressive and tensile strength at optimal replacement levels.

Xu et al. [7] focused on the use of recycled ceramic aggregates for internal curing of HPC, revealing that ceramic aggregates with higher porosity offer better shrinkage control, while lower replacement ratios provide higher strength. Sivakumar et al. [8] studied the effects of replacing fine and coarse aggregates with ceramic waste in varying proportions, concluding that the ideal replacement ratio was 20% for enhancing mechanical properties. Hamada et al. [9] reviewed the potential of using solid waste in ultra-high-performance concrete, emphasizing the benefits of improved durability and microstructure through waste-based binders.

Jwaida et al. [10] provided a comprehensive review of the use of waste ceramic in concrete, stressing its positive impact on reducing landfill waste and promoting sustainability. Rao et al. [11] explored the inclusion of quartz and eggshell powders as supplementary materials, observing enhancements in both compressive and tensile strength. Anitha et al. [12] demonstrated the effectiveness of Alccofine 1203 as a partial cement replacement, improving both strength and durability at a 10% substitution level.

3 MATERIALS USED

The materials used in this study are as follows:

1. Cement
2. Fine Aggregate
3. Coarse Aggregate
4. Water
5. Ceramic Insulator Waste

3.1 Cement

The cement used in this study is Ordinary Portland Cement (OPC) of 53 grade, which was sourced from the local market. All tests were performed using cement from the same batch, following IS: 4031-1988 standards. The cement meets the specifications of IS: 12269-1987 for strength, setting time, and fineness.

3.2 Fine Aggregate

The fine aggregate used in this study is well-graded river sand, sieved to pass through a 4.75 mm sieve, ensuring it is free from foreign particles. The following tests were conducted on the fine aggregate: water absorption capacity, specific gravity, and fineness modulus. The sand was air-dried before use.

Table 1. Physical properties of aggregate

S. No.	Property	Test Method	Test Results	IS Standard
1.	Normal Consistency	Vicat Apparatus (IS:4031 Part-4)	29.5%	-
2.	Specific Gravity	Sp. Gr Bottle (IS:4031 Part-4)	3.10	-
3.	Initial Setting Time	Vicat Apparatus (IS:4031 Part-4)	53 minutes	Not less than 30 minutes
	Final Setting Time		493 Minutes	Not less than 10 hours
4.	Fineness	Sieve test on sieve no.9 (IS: 4031 Part -1)	5%	10%
5.	Soundness	Le-Chatlier method (IS: 4031 Part-3)	2mm	Not more than 10mm

3.3 Coarse Aggregate

The coarse aggregate used is crushed blue granite with a maximum size of 20 mm. Tests conducted include water absorption capacity, specific gravity, and fineness modulus to ensure compliance with standards.

3.4 Water

Fresh potable water was used for both mixing and curing in this study, meeting the standards of IS: 3025 – 1964 (part 22, part 23) and IS: 456 – 2000. The water was free from contaminants, ensuring proper hydration and strength development in the concrete.

3.5 Ceramic Insulator Waste

CIW is utilized as a sustainable material in this study, replacing a portion of the coarse aggregate. CIW is derived from discarded ceramic insulators, offering advantages like low water absorption, high specific gravity, and favourable particle size distribution. CIW is chemically inert, making it compatible with cement and other aggregates.

Table 2. Properties of Ceramic Insulator Waste (CIW)

Property	Test Method	Value
Specific Gravity	ASTM C127	2.5 - 3.0
Water Absorption	ASTM C70	2% - 5%
Particle Size Distribution	Sieve Analysis	Well-graded
Chemical Composition	XRF Analysis	Inert
Thermal Stability	Thermogravimetric Analysis	Stable up to 1200°C

4 RESULTS AND DISCUSSIONS

4.1 Under Normal Water Curing Conditions

4.1.1 Compression Strength

This section presents the compressive strength results obtained from testing concrete samples with varying percentages of CIW replacement. The samples were cured under normal water conditions for 7, 14, and 28 days, and the compressive strength was measured to assess the influence of CIW on the performance of the concrete mixes. Table 3 summarizes the average compressive strength values (in N/mm²) for each percentage of CIW replacement at different curing durations. Fig. 1 illustrates the compressive strength values.

The results demonstrate that compressive strength varies with the percentage of CIW replacement. Generally, the incorporation of CIW up to 4% leads to an improvement in compressive strength. However, beyond this threshold (at 6% and 8% CIW replacement), a noticeable reduction in compressive strength occurs. This suggests that higher CIW content negatively affects the mechanical properties of the concrete mixes. Additionally, the variability in results between different trials emphasizes the importance of conducting multiple trials to account for potential fluctuations in material properties and testing conditions.

Table 3. Average compressive strength values

Ceramic Insulator Waste (CIW)	Trial	Load	Average load	Compressive Strength	Load	Average load	Compressive strength	Load	Average load	Compressive strength
		kN	kN	(N/mm^2)	kN	kN	(N/mm^2)	kN	kN	(N/mm^2)
		7 days			14 days			28 days		
0%	1	400	400	17.77	520	510	22.66	700	696.7	30.96
	2	380			500			690		
	3	420			510			700		
2%	1	410	406.3	18	530	536.3	23.85	700	710	31.55
	2	410			540			710		
	3	400			540			720		
4%	1	410	416.3	18.5	540	540	24.05	700	723.3	32.15
	2	420			530			710		
	3	410			550			710		
6%	1	380	370	16.44	510	480	21.33	680	683.3	30.37
	2	370			470			700		
	3	360			460			670		
8%	1	350	353.3	15.7	440	426.7	18.96	680	673.3	29.92
	2	370			410			660		
	3	340			430			650		

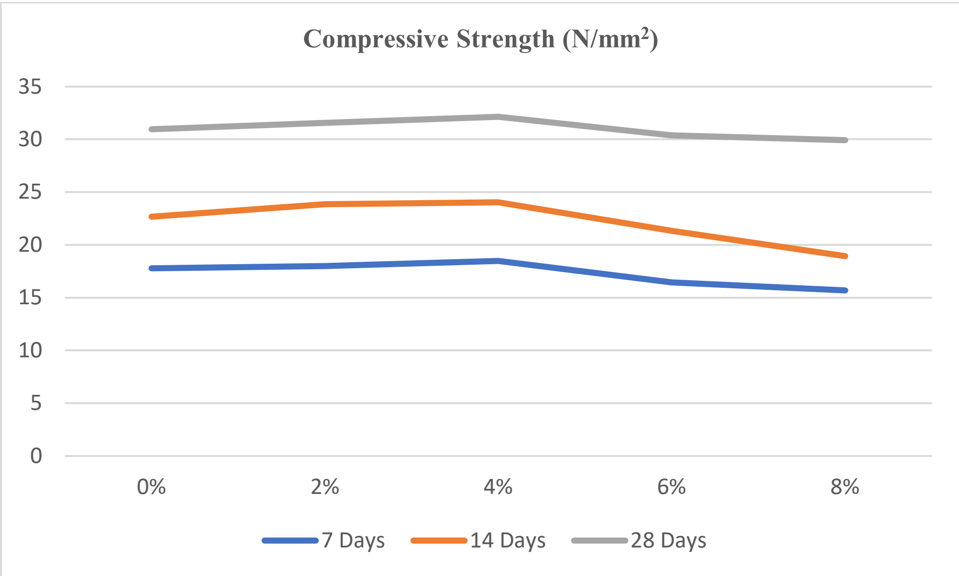

Fig. 1 Average compressive strength

4.1.2 Split Tensile Strength of CIW Concrete

The split tensile strength of concrete with varying percentages of CIW was measured at 7, 14, and 28 days under normal water curing conditions. The results are summarized in Table 4 below. The corresponding trend of split tensile strength over different CIW percentages and curing durations is illustrated in Fig. 2. Based on the data provided in Table 4 and Fig. 2, the optimum mix percentage for CIW concrete can be identified by analyzing the split tensile strength values at 7, 14, and 28 days. The mix with 2% CIW demonstrates the highest split tensile strength across all curing durations, making it the optimal replacement level in this context.

International Journal of Emerging Research in Engineering, Science, and Management
Vol. 3, Issue 4, pp.11-19, Oct-Dec 2024.
www.ijeresm.com eISSN – 2583-4894

Table 2 Split Tensile Strength values at 7, 14, and 28 days

Ceramic Insulator Waste	Load	Split Tensile Strength	Load	Split Tensile Strength	Load	Split Tensile Strength
	kN	(N/mm²)	kN	(N/mm²)	kN	(N/mm²)
	7 Days		14 Days		28 Days	
0%	112	1.57	152	2.13	201	2.83
2%	123	1.72	173	2.45	232	3.25
4%	105	1.43	158	2.27	215	3
6%	93	1.28	138	1.98	193	2.7
8%	66	0.87	121	1.7	161	2.26

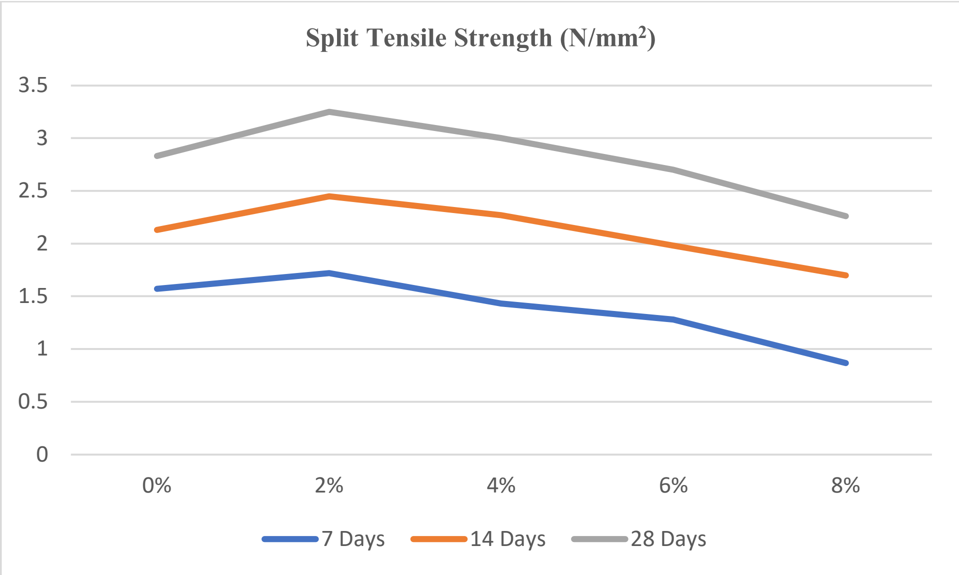

Fig. 2 Average Split Tensile Strength (N/mm²)

4.1.3 Flexural Strength

The flexural strength of concrete incorporating varying percentages of CIW was measured at 7, 14, and 28 days, with the results summarized in Table 5 below.

Table 5. Flexural Strength values for 7, 14, and 28 days

Ceramic Insulator Waste (%)	Flexural Strength (N/mm²) at 7 Days	Flexural Strength (N/mm²) at 14 Days	Flexural Strength (N/mm²) at 28 Days
0	1.77	2.3	2.99
2	1.86	2.63	3.6
4	1.63	2.52	3.26
6	1.51	2.23	2.92
8	1.09	2.07	2.38

The corresponding graph illustrating the trend in flexural strength is presented in Fig. 3. From the data in Table 5 and Fig. 3, it is observed that the flexural strength tends to increase with CIW replacement up to 4%, after which it begins to decline. Therefore, 4% CIW appears to be the optimum percentage, yielding relatively high flexural strength across all curing durations. Beyond this level, the decrease in flexural strength suggests that higher percentages of CIW are less effective for enhancing the flexural performance of the concrete.

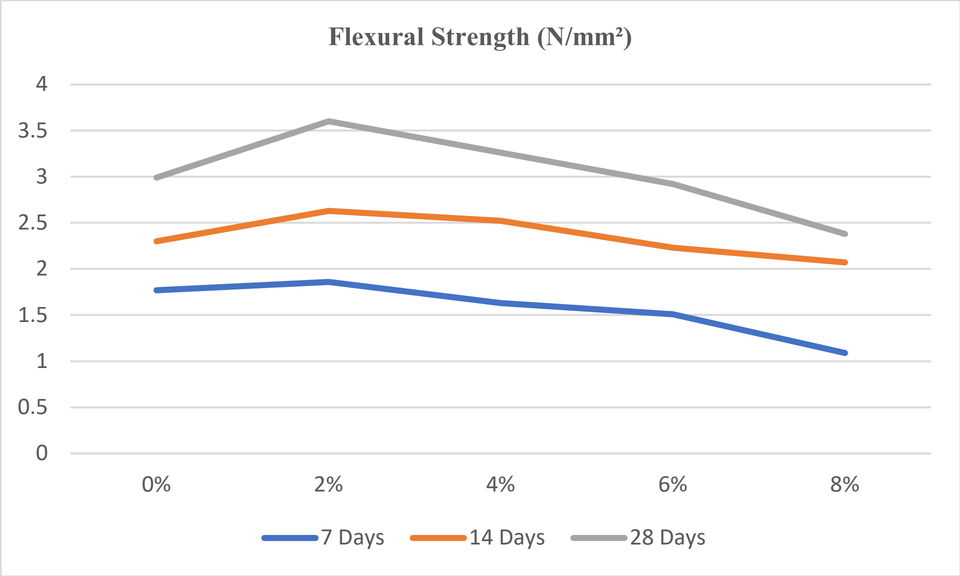

Fig. 3 Flexural Strength (N/mm^2)

4.2 Under Acidic Water Curing Conditions

4.2.1 Compressive Strength

The compressive strength of concrete under acidic water curing conditions for varying percentages of Ceramic Insulator Waste is summarized in Table 6. The corresponding trend of compressive strength over different curing durations is illustrated in Fig. 4.

Table 6. Compression strength values under acidic water curing conditions

CIW (%)	7-day Strength (N/mm^2)	14-day Strength (N/mm^2)	28-day Strength (N/mm^2)
0	17	21.5	29.5
2	17.5	22.5	29.7
4	18	22.8	30.2
6	16	20.5	28.5
8	15.5	18	28

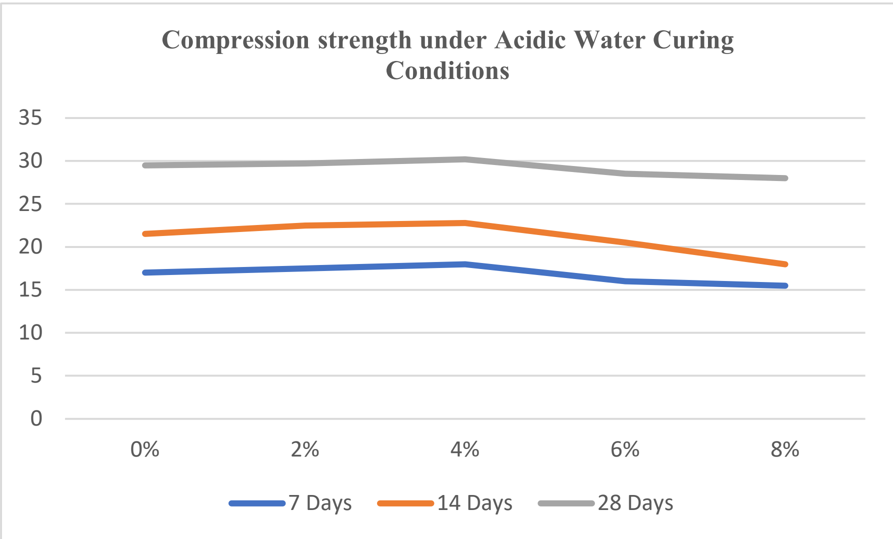

Fig. 4 Compression strength values Under Acidic Water Curing Conditions

From the data, it is observed that the compressive strength increases up to 4% CIW incorporation, after which it declines slightly. This trend is consistent across all curing durations (7, 14, and 28 days), suggesting that 4% CIW yields the highest compressive strength under acidic conditions.

International Journal of Emerging Research in Engineering, Science, and Management
Vol. 3, Issue 4, pp.11-19, Oct-Dec 2024.
www.ijeresm.com eISSN – 2583-4894

4.2.2 Split Tensile Strength (N/mm²)

The split tensile strength results for concrete under acidic water curing conditions are shown in Table 7. Fig. 5 depicts the trend in split tensile strength. The results indicate that 4% CIW provides the highest tensile strength values across all curing durations.

Table 7. Tensile Strength values under acidic conditions

Ceramic Insulator Waste (%)	7-day Strength	14-day Strength	28-day Strength
0	1.45	1.9	2.6
2	1.5	1.95	2.65
4	1.55	2	2.7
6	1.4	1.8	2.5
8	1.35	1.6	2.45

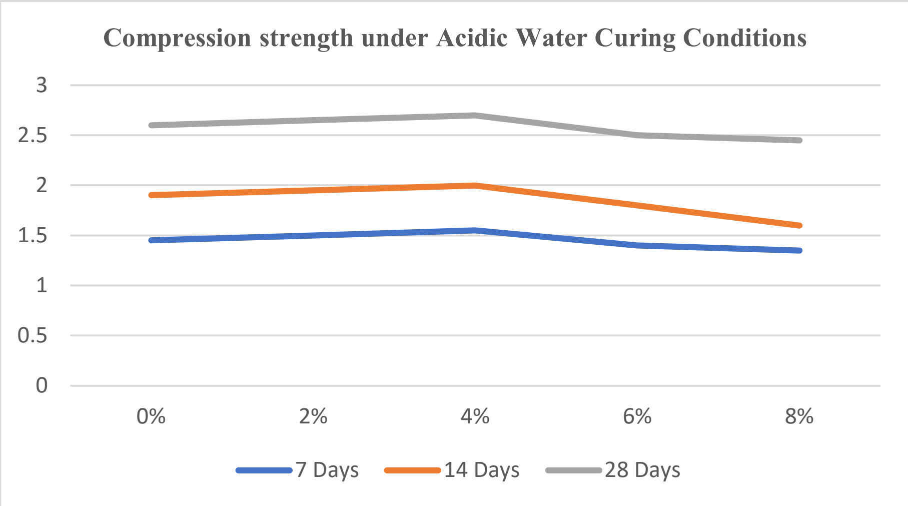

Fig. 5 Compression Strength under Acidic Water Curing Conditions

4.2.3 Flexural Strength (N/mm²)

The flexural strength values for concrete under acidic water curing conditions are presented in Table 8. Fig. 6 shows the flexural strength trend. The results highlight that 4% CIW offers the best flexural strength under acidic water curing conditions.

Table 8. Flexural Strength values under acidic conditions

Ceramic Insulator Waste (%)	7-day Strength	14-day Strength	28-day Strength
0	1.6	2.1	2.8
2	1.65	2.15	2.85
4	1.7	2.2	2.9
6	1.55	2	2.7
8	1.5	1.8	2.65

Based on the results obtained under acidic water curing conditions, 4% CIW is the optimum replacement percentage, providing superior mechanical properties across all curing durations. Beyond this percentage, there is a noticeable decline in strength values, indicating that higher percentages of CIW may not be as beneficial for improving the mechanical properties of concrete under acidic conditions.

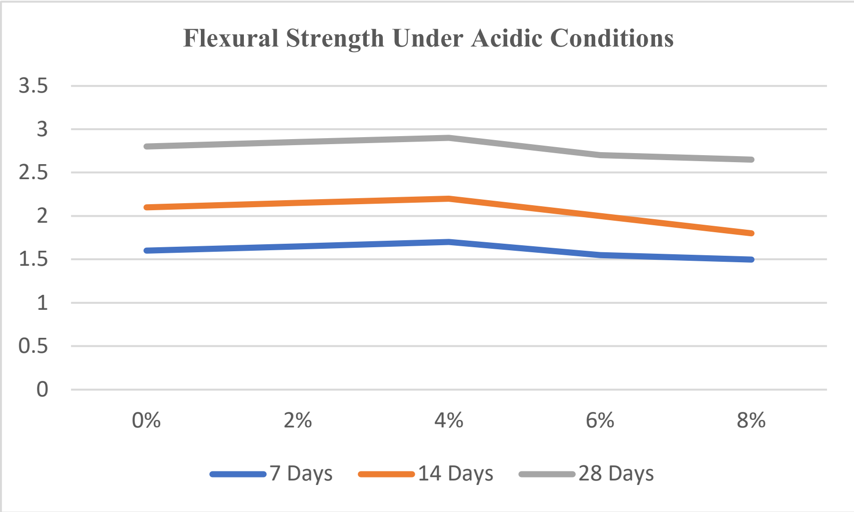

Fig. 6 Flexural Strength under Acidic Water Curing Conditions

5 CONCLUSIONS

This study investigated the incorporation of Ceramic Insulator Waste as a partial replacement for coarse aggregate in concrete, evaluating its impact on various mechanical properties under both normal and acidic water curing conditions. The primary objective was to assess the effectiveness of CIW at different percentages to determine its optimal usage in concrete production. The results revealed that the mechanical properties of concrete—specifically compressive strength, split tensile strength, and flexural strength—were significantly influenced by the percentage of CIW replacement. Under normal water curing conditions, an increase in CIW content generally led to a reduction in strength. This reduction was particularly pronounced at higher CIW replacement percentages of 6% and 8%, indicating a negative correlation between CIW content and concrete performance beyond 4%. Similarly, under acidic water curing conditions, the mechanical properties followed the same trend, with a decline in strength as the CIW percentage increased. Across all parameters and curing conditions, 4% CIW replacement consistently emerged as the optimal percentage for achieving favourable strength characteristics, while higher percentages resulted in diminished performance. The use of CIW as a partial aggregate replacement shows potential as a sustainable practice, with 4% being the most suitable replacement level for maintaining mechanical performance. This study contributes to ongoing efforts to incorporate waste materials into construction, reinforcing the importance of balancing sustainability with performance. Further research should focus on long-term durability, environmental impact, and economic feasibility to offer a comprehensive understanding of CIW's role in sustainable concrete production.

ACKNOWLEDGEMENT

The authors would like to sincerely thank the Department of Civil Engineering, Bonam Venkata Chalamayya Engineering College (Autonomous), Odalarevu, for providing invaluable support throughout this research for the access to the necessary hardware and equipment, which greatly contributed to the successful completion of this research.

FUNDING INFORMATION

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

ETHICS STATEMENT

This study did not involve human or animal subjects and, therefore, did not require ethical approval.

STATEMENT OF CONFLICT OF INTERESTS

The authors declare no conflicts of interest related to this study.

REFERENCES

[1] J. Xiao, J. Li, and Ch. Zhang, "Mechanical properties of recycled aggregate concrete under uniaxial loading," *Cement and Concrete Research*, vol. 35, no. 6, pp. 1187–1194, Dec. 2004, doi: 10.1016/j.cemconres.2004.09.020.

[2] B. Craeye, M. Geirnaert, and G. De Schutter, "Super absorbing polymers as an internal curing agent for mitigation of early-age cracking of high-performance concrete bridge decks," *Construction and Building Materials*, vol. 25, no. 1, pp. 1–13, Jul. 2010, doi: 10.1016/j.conbuildmat.2010.06.063.

[3] M. Behera, S. K. Bhattacharyya, A. K. Minocha, R. Deoliya, and S. Maiti, “Recycled aggregate from C&D waste & its use in concrete – A breakthrough towards sustainability in construction sector: A review,” *Construction and Building Materials*, vol. 68, pp. 501–516, Jul. 2014, doi: 10.1016/j.conbuildmat.2014.07.003.

[4] J. Bommisetty, T. S. Keertan, A. Ravitheja, and K. Mahendra, “Effect of waste ceramic tiles as a partial replacement of aggregates in concrete,” *Materials Today Proceedings*, vol. 19, pp. 875–877, Jan. 2019, doi: 10.1016/j.matpr.2019.08.230.

[5] B. A. Tayeh, D. M. A. Saffar, and R. Alyousef, “The utilization of recycled aggregate in high performance concrete: a review,” *Journal of Materials Research and Technology*, vol. 9, no. 4, pp. 8469–8481, Jun. 2020, doi: 10.1016/j.jmrt.2020.05.126.

[6] M. Amin, A. M. Zeyad, B. A. Tayeh, and I. S. Agwa, “Effects of nano cotton stalk and palm leaf ashes on ultrahigh-performance concrete properties incorporating recycled concrete aggregates,” *Construction and Building Materials*, vol. 302, p. 124196, Jul. 2021, doi: 10.1016/j.conbuildmat.2021.124196.

[7] F. Xu, X. Lin, A. Zhou, and Q.-F. Liu, “Effects of recycled ceramic aggregates on internal curing of high performance concrete,” *Construction and Building Materials*, vol. 322, p. 126484, Jan. 2022, doi: 10.1016/j.conbuildmat.2022.126484.

[8] A. Sivakumar, S. Srividhya, V. Sathiyamoorthy, M. Seenivasan, and Subbarayan, “Impact of waste ceramic tiles as partial replacement of fine and coarse aggregate in concrete,” *Materials Today Proceedings*, vol. 61, pp. 224–231, Aug. 2021, doi: 10.1016/j.matpr.2021.08.142.

[9] H. M. Hamada, J. Shi, F. Abed, M. S. A. Jawahery, A. Majdi, and S. T. Yousif, “Recycling solid waste to produce eco-friendly ultra-high performance concrete: A review of durability, microstructure and environment characteristics,” *The Science of the Total Environment*, vol. 876, p. 162804, Mar. 2023, doi: 10.1016/j.scitotenv.2023.162804.

[10] Z. Jwaida, A. Dulaimi, and L. F. A. Bernardo, “The Use of waste ceramic in Concrete: a review,” *CivilEng*, vol. 5, no. 2, pp. 482–500, May 2024, doi: 10.3390/civileng5020024.

[11] Allu Taraka Rama Rao, Ravi Kumar, Chandra Mouli V.S.A, “Performance Study of Plain cement concrete containing quartz powder and eggshell powder as partial replacement of cement,” *International Journal of Emerging Research in Engineering, Science, and Management*, vol. 3, issue 3, pp. 59-69, July-Sep 2024, doi: 10.58482/ijeresm.v3i3.10.

[12] Vipparthi Anitha, P. Gnanamoorthy, Ch. Sivanarayana, “Enhancing the Performance and Durability of M35 Grade Concrete with Alccofine 1203,” *International Journal of Emerging Research in Engineering, Science, and Management*, vol. 3, issue 4, pp. 01-10, Oct-Dec 2024, doi: 10.58482/ijeresm.v3i4.1.