Study on Performance, Strength and Durability Of Metallic And Non-Metallic Fibre Reinforced Concrete With Inclusion Of Waste Ceramic Aggregates – A Review

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ABSTRACT
Every year, the world generates millions of tons of waste, much of which cannot be recycled due to the high energy consumption and pollution involved in the recycling process. Ceramic is increasingly used in modern construction, especially in the production of tiles, but the material's fragility causes significant waste during processing, transportation, and installation. Even recycling the waste ceramic for further processing is currently not feasible. However, by using waste ceramic as a material in concrete production in the right way, we can eliminate waste and improve the properties of concrete. As the sustainable or green concrete industry continues to expand, many metallic and non-metallic wastes are generated in each processing and usage stage. This review article examines the utilisation of alternative materials in concrete to find solutions for waste disposal and provides construction contractors and developers with a vast range of ideas to improve and adopt new construction methods. The paper also gives a brief review of the properties from concrete produced from waste ceramic can be utilised as replacement for coarse aggregates by metallic and non-metallic fibers, and the resulting hardened concrete properties are studied.

Keywords: *Ceramic tiles, Sustainable, Metallic, Non-metallic, Fibers.*
Short Forms:- *Ceramic waste-(CEW),Coarse natural aggregates-(CNA), Ceramic aggregates-(CEA)*

INTRODUCTION

It is commonly known that concrete is a popular building material worldwide due to its easy availability, low maintenance requirements, and strength and durability. Recent reports estimate that structural industry necessitates 1.5 billion metric tons cement, 15 to 20 billion tons aggregate, also around 1 billion tons of the water, also Globally, construction waste reaches 2.2 billion tons, accounting for 23% of all waste produced worldwide. In India, approximately 150 million tons of construction waste is generated annually. With the increasing world population, the demand for concrete is also increasing (2). However, the heavy extraction and use of sand and gravel for concrete production have significant negative impacts on the environment. To address this issue and reduce environmental harm, the International Energy Agency recommends the practice of alternative materials used to substitute natural aggregates.

The industry consumes massive amounts of cement, aggregate, and water globally. Construction waste, particularly from the demolition sector, contributes to a significant portion of overall waste production. In India alone, 150 million tons of construction waste is generated annually and worldwide 2.2 billion tons of waste is generated i.e., 23% from C&D sector (2). With the global population steadily increasing, Therefore, the need for concrete. Unfortunately, the extraction of sand and gravel for concrete production has severe environmental consequences. To mitigate these issues, the International Energy Agency suggests substituting natural aggregates with alternative materials.

The construction and industrial sectors are the only feasible resources for alternative different materials for concrete aggregate manufacture[17][25]. One promising option is the utilization of waste ceramic, which could lower the price of producing concrete and be eco-friendlier. Waste ceramic aggregates can be utilized as alternative of natural aggregates in both fine and also in coarse forms, as well as they have been discovered a way to increase the characteristics of concrete[4][21]. Additionally, metallic as well as non-metallic fibers will be added in to the concrete mix for further boost its properties and workability.

In summary, the construction industry urgently needs sustainable aggregates, and waste ceramic aggregates can potentially fulfil this need. By using waste ceramic aggregates, we can reduce the detrimental environmental effect produced by sand and gravel extraction while also improving the properties of concrete.

CHEMICAL COMPOSITION OF CERAMIC

Ceramics have a diverse range of chemical compositions according to their functions. Alumina (Al2O3) for mechanical strength, zirconia (ZrO2) for high-temperature applications, and silicon dioxide (SiO2) for transparency and heat resistance are common components. Iron oxides (Fe2O3) or calcium oxides (CaO) are frequently used as colouring agents in traditional ceramics. To get certain qualities, traces of metal oxides, such as titanium dioxide (TiO2), might be added. Glass ceramics contain glass-forming chemicals like boron oxide (B2O3) whereas non-oxide ceramics like silicon carbide (SiC) offer remarkable toughness. Ceramics thrive in a wide range of applications, including structural engineering and aesthetic creations.

Table1:-chemical composition of ceramic and cement[3]

Materials	Waste Ceramic Powder (C_{WC})	Cement (OPC 43)
SiO_2	68.85	22.18
Al_2O_3	17	7.35
Fe_2O_3	0.8	3.83
CaO	1.7	63.71
Na_2O	_	0.28
K_2O	1.63	0.11
MgO	2.5	0.95
TiO_2	0.737	0.13
MnO	0.078	0.04
LOI	1.78	1.6

INFLUENCE OF FIBERS ON CONCRETE:

Fibers show complex influence on properties of concrete, making them an advantageous addition in a variety of building contexts. First and foremost, they work well as crack-controlling agents, especially when it comes to reducing shrinkage and heat cracks.

Because of the improved fracture resistance, concrete structures are stronger and can endure the rigors of varied climatic conditions and mechanical pressures.

Moreover, fibers considerably progress flexural and also tensile strength in concrete, making it appropriate for demanding applications such as pavement. Key characteristics include increased toughness and ductility, which enable concrete to withstand unexpected loads and shocks and increase resilience in addition, fibers are crucial for reducing shrinkage and plastic cracking, maintaining the surface quality, and adding aesthetic value, which is crucial for projects involving ornamental concrete[23].

Certain fibers increase the concrete's resilience in areas that experience freeze-thaw cycles, reducing damage from the expansion of frozen water. Some fiber kinds also improve fire resistance, guaranteeing structural stability at high temperatures.

Due to its enduring structural integrity, fiber-reinforced concrete frequently results in cheaper maintenance costs over time. In order to achieve the necessary performance characteristics, careful consideration must be given in the mix design to the unique effect of fibers, which depends on elements like fiber type, aspect ratio, and dose.

DURABILITY

As the amount of RWCA in mixture grows, breadth of cracks in concrete mixtures containing RWCA tend to widen[13]. In other contrast, adding of Wire-Cut Fibers (WCF) results in a 55% reduction in fracture width. This decrease happens as a result of the fissures' breadth being reduced by the fibers' ability to bridge and span over them. [2]

The composites made from white and red ceramic waste have good mechanical characteristics that allow them to be classified into standard strength categories in accordance with both EN (European Norms) and the 2010 fib Model Code. [4]

The inherent capillary force within the cement paste is significantly reduced as a result of minimizing autogenous shrinkage by including PCCA. This decline is relational to decline in autogenous shrinkage. [6][9] Between 10% and 30% is the best range for employing leftover ceramic tiles as coarse aggregates. Within this range, the compressive strength increases while the unit weight decreases as well. [7] Waste from recycled ceramic toiletries may be used as an aggregate in the creation of concrete.

This kind of aggregate makes it possible to produce easily workable concrete mixtures that, once dried, result in concrete with remarkable strength properties. [5][11] As the fiber content increased, ceramic concrete's Compression resilience indicator, flexural toughness, also shear toughness all significantly enhanced. No matter the kind of matrix or the size of the fibers. [13]

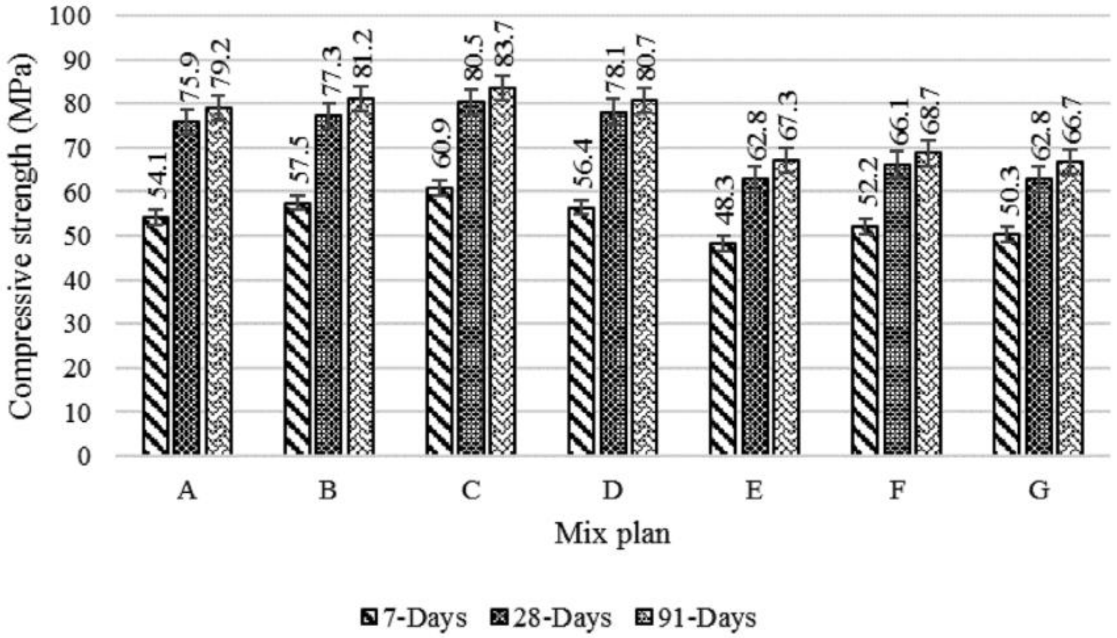

***Fig.1:**-Compressive strength of ceramic based fiber reinforced concrete [2]*

MICRO STRUCTURE CHARACTERIZATION OF CERAMIC FIBER REINFORCED CONCRETE

Numerous studies have examined the microstructure of ceramic fiber reinforced concretes and mortars. In general, a number of methods and instruments (including XRD, SEM, and EDS) are used to examine the microstructure of concrete. XRD analysis has adopted to identify mineral phases along with chemical composition for materials.

SEM analysis was employed to characterize the microstructure and identify the interfacial transition zone. It is referred to as interfacial transition zone (ITZ) when the cement pastes and aggregates are in contact. Concrete's strength, stiffness, and permeability are some of the mechanical characteristics that have an impact on this ITZ. The WOC SEM micrographs revealed a minor amount of surface porosity and a small size of potential microcracks. It has been noted that some of the C-S-H gel seems to possess broken down to smaller subdivisions along with calcium hydroxide crystal remnants. Test has revealed minute round particles that seemed to be unreacted cement and feldspar filling the surface area, both of which positively correlated Regarding the response to compression in terms of strength characteristics. [3] The SEM micrographs in ceramic based plastic fiber concrete, which was seen from the 2%PF-ICB and the control-ICB revealed ettringite, which had grown as a result of the relatively higher ceramic concentration. Ettringite development takes place in the early phases of concrete curing as a safeguard against quickly setting cement. However, the presence of ettringite in mature concrete suggests that cement hydration is still incomplete, which might result in further expansion. As a result, the concrete material's strength was reduced. According to results of the test, when cement was hydrated with the WCP, the angular cement particles were encircled by calcium silicate hydrate (C-S-H) fibers that spread outward, simulating the C-S-H pattern seen in regular cement.

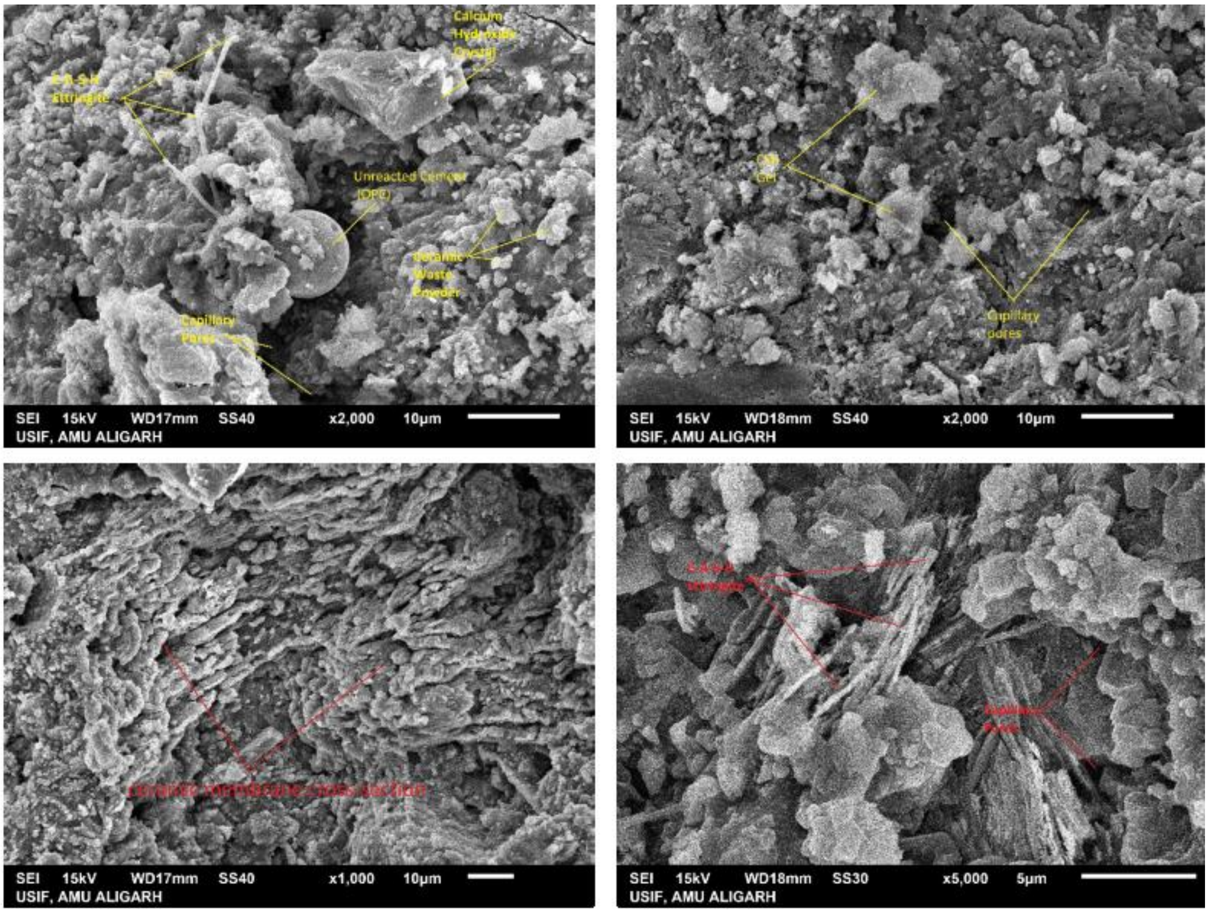

***Fig.2:**-SEM OF Waste Optimal Concrete[3]*

CERAMIC USED IN CONCRETE WITH METALLIC AND NON-METALLIC FIBERS

Bartosz zegardło et al [1] examines the heat resistance characteristics in concrete by utilizing RCEA instead of coarse aggregates(CA), and adding carbon fibers and polypropylene fibers(2% by volume). found that by adding carbon fibers, the compressive strength increased significantly to 30% compared to the use of traditional additives. Moreover, when subjected to an annealing process, the carbon fibers showed 3.1 times greater tensile strength than polypropylene fibres. Zareei et al [2] conducted investigation of High strength concrete (HSC) characteristics that replaces coarse aggregate with discarded carpet fibers (1% by volume) and ceramic aggregates(CEA) at varying percentages (20%, 40%, and 60% by weight). The results revealed that using 40% recycled CEA improved both the compression & tensile strength by 13%, 15%, 3% in concrete in comparison to traditional mixes after 28days test. Additionally, use of carpet fibers increased the tensile strength by 21% when combined with the recycled ceramic aggregate mix. Hadee Mohammed Najm et al [3][11] conducted research on mechanical & microstructural characteristics of concrete where Waste CEA were taken to substitute with CA, and hybrid fibers were included. By adding polyvinyl alcohol and crimped steel fibers, the tensile along with flexural strength in concrete increased 84% and 68-72% correspondingly. Additionally, an increase in pore filling was observed, resulting in a dense, compact structure which directly leads higher durability and increased crack strength. Katzer et al [4] explored the properties in concrete made by substituting

CNA by CEW aggregates along with adding crimped steel fibers. Four samples were made with varying proportions of ceramic aggregates (0%, 33%, 67% and 100% by weight) and also with crimped steel fibers(0%, 0.5%, 1%, 1.5%). Observed that compressive strength in concrete has increased when only natural aggregates were used. However, when ceramic aggregates were used in combination with crimped steel fibers(1.5%), the increase in strength was not significant, but the results were still satisfactory. Awoyera et al [6] examines specific characteristics using the method of replacing 20% of fine aggregate along ceramic waste along with adding polypropylene fibers of varying amounts (0%, 0.5%, 1%, 1.5%, also 2% based on weight of concrete). Multiple samples in 7, 28, and 90-day tests observed that compressive strength along with tensile properties in concrete blocks improved with higher polypropylene fiber composition. At a micro scale, the concrete exhibited good compactness and inter-particle reaction. Suzuki et al [7] investigates the effectiveness of internal curing in HP concrete using recycled porous ceramic waste coarse aggregates(CWCA). Six samples were produced, with silica HP concrete along with and without recycled porous CWCA. After 28 days, the results observed that incorporating 10-20% of CEWA in concrete mix with less w/b ratio around 0.17, significantly reduced autogenous shrinkage also reduced the possibility of early cracking. It was observed from here on increasing the proportion of recycled waste ceramic aggregate leaded significant decrease in autogenous shrinkage and tensile stresses. When 40% of the volume of the concrete was replaced along RWCA(recycled waste ceramic aggregate), along with autogenous shrinkage was reduced by 30%-105% and there was a drastic raise in compressive strength. Daniyal et al [8] examined the properties of concrete using crushed(pulverized) ceramic tiles as a substitute of CA at varying levels of substitution (10%, 20%, 30%, 40%, and 50%). The observation shows that the best results was achieved thru 30% substitution also w/c ratio 0.55, resulted 5% rise of compressive strength also 32% increase of flexural strength observed Compared to the standard concrete. Mohit et al [10] examined characteristics for cement mortar, particularly its mechanical and long-lasting qualities. To substitute cement, the author used limestone powder (LSP) and ceramic waste powder (CWP) in varying proportions (10%, 20%, and 30%) and produced samples. Based on the outcomes, it was discovered that the mixture of 10% CWP & 15% LSP resulted in greatest compressive strength, while 30% CWP & 15% LSP resulted in least compressive strength than the reference sample. Meena et al [12] Research involved the utilization of waste ceramic tile aggregate (WCTA) to create sustainable self-compacting concrete (SSCC). A total of six samples were analyzed (0%, 20%, 40%, 60%, 80% and 100%), and it was found that replacing 60% of the weight with WCTA resulted in improvement in compressive strength, tensile strength & flexural strength. Also, microstructural characteristics are known by XRD and FTIR technique. However, as proportion based on WCTA was increased beyond this point, there was a sharp decline in these values. Arias-Trujillo et al [14] Researched ways to enhance the geotechnical characteristics of aeolian soil for use in Jeddah's sandy environment. To accomplish this, three different mixtures of ceramic brick waste aggregates (CBWA) were tested in ratios of 15%, 30%, and 45%. Following the testing, it was discovered that the addition of 45% CBWA to the sand increased confinement uniformity from 2.37 to 3.56 and resulted in a 33% higher CBR ratio than pure aeolian soil. Halicka et al [15] Studied the characteristics of concrete that contained alumina cement. Ceramic sanitary ware waste was used as both the coarse and fine aggregate, and specimens with natural aggregates were also prepared. All of the specimens were heated to 1000°C. The specimens that were continuously heated showed high compressive and tensile strength, as well as high abrasion resistance. Overall, the results propose that ceramic concrete might be a good material for use in areas with high temperatures. Gondokusumo et al [16] The author of the paper conducted an experiment on flexural mechanical strength of concrete that with both lightweight and reinforced with steel fibers. A total of 60 prism specimens, including normal, lightweight, and fiber-reinforced concrete, were heated to 200°C to 800°C, and their flexural strength was measured. It was observed that the flexural tensile SFRC decreased as the temperature increased. The researcher also performed a regression analysis for forecasting strength retention factors. Tassew et al [18] performed an experiment on mechanical characteristics of ceramic concrete(CEC) that was reinforced along with glass fibers. Two matrices were tested: one without fibers and another with 2% glass fibers (by volume). Results displayed that fibers inclusion leaded to a 33% improvement of flexural strength, along with an increase in modulus of elasticity, compared to compressive strength. However, also observed that with rise in fiber quantity workability of mixture decreased. Talaei et al [19] conducted a study on mechanical properties on 120 cylindrical specimens that were made using waste porcelain as an aggregate. Ordinary Portland cement, fibers, and refractory cement were also included in the specimens, which were exposed 400°C- 800°C. Results showed that all of the specimens experienced a decrease in both compressive and tensile strength. The highest strengths were obtained when OPC was used at 400°C, and when refractory cement was used at 800°C. The inclusion of steel fibers leaded to a strength improvement of 20%-30% at both 400°C and 800°C, while polypropylene fibers did not increase the mechanical properties but did decrease the spalling effect. Ozawa et al [22] Carried out a test to investigate reduction in the spalling effect on ultra-high-performance concrete(UHPC) flashed with high temperatures. The study involved using waste porous ceramic fine aggregate(WPCEFA) as the internal curing agent instead of regular aggregate. Additionally, polypropylene along with jute fibers were included in the mixture. The findings revealed that the inclusion of the internal curing material resulting in a decrement in autogenous shrinkage of UHPC. It was also observed that inclusion in fiber content leaded to a decrease of compressive strength in mixture. Furthermore, when 0.5% jute fiber was added to the mix (0.5% jute fiber + internal curing material + UHPC), the spalling period was significantly reduced compared to the normal UHPC mix. Ray et al [24] conducted investigation comparing the efficiency of two machine learning techniques, Support Vector Machine (SVM) and also Gradient Boosting Machine (GBM). The study focuses for evaluate the performance from these techniques using a mixture composed of ceramic waste(CEW) along with nylon fiber. Total around 162 records from compressive and split tensile tests were considered, involving nine different mix proportions, the data is evaluated by splitting statistics 80% in training & 20% for the testing. Mechanical tests are performed at 7days, 14 days and 28days. The exercise data included constraints such as contents of cement, sand, stone, ceramic, nylon fibre and others. The outcomes show that both SVM and GBM yielded comparative qualities, yet GBM displayed more noteworthy precision in foreseeing compressive and split malleable experimental outcomes. Gaibor et al [26] performed an experiment aimed at enhancing the characteristics of alkali-activated mortar by incorporating polyacrylonitrile fibers. The objective is to improve the characteristics of the mortar by use of ceramic waste from clay bricks as the primary material along with furnace slag and sodium silicates. By adding different percentages of fibers (0%, 0.5%, 1% by volume) and testing the mortar at different time intervals (14 days, 28 days, 90 days), the mechanical properties showed a 20% improvement compared to mortar without fibers. Cherene et al [27] The sand was replaced with waste ceramic aggregate in varying proportions: 10%, 20%, and 30%, with an additional reference sample containing 0% replacement. The results indicated that when the replacement was 10%, the mechanical along with microstructural properties in concrete showed improvement than the 20% and 30% replacement samples. Additionally, the concrete with 10% replacement exhibited a dense and compact structure. Taher et al [28] performed an experimental study aimed at developing sustainable and eco-friendly concrete. To achieve this, the author utilized ceramic waste tile powder acting as partial alternative to fine aggregate for two samples: one with 10% replacement and another with 20% replacement. Both burned and unburned samples were examined. The results indicated that the 10% replacement in both burned and unburned samples exhibited favourable mechanical properties and offered environmental advantages by reducing the need for landfills. Lam et al [29] conducted an experiment using Taguchi and Box-Behnken design method for enhancing compressive strength along with durability by utilizing the clay brick and ceramic waste. The results revealed that incorporating clay brick leaded to an raise in compressive strength. However, when ceramic waste is utilized as fine aggregate, then compressive strength significantly decreased. Also, with ceramic waste as coarse aggregate resulted 100% raise of compressive strength. While compressive strength obtained after 7-day test was low, satisfactory levels of compressive strength were achieved at 28 days. Additionally, the concrete demonstrated high resistance to sulphate attack and chloride ion penetration. Abou Rachied et al [30] directed an examination to research the shafts underlying way of behaving produced using ordinary and furthermore high strength cements mixed with the clay squander powder and impact heater slag. Two mixes were prepared, one with a compressive strength of 34 MPa and another with 71 MPa. The beams, reinforced with steel, were cast up to a length of 2 meters. It is demonstrated that inclusion of 10% ceramic waste enhanced the structural properties of beams. The reduction in flexural strength is mitigated from using a ternary binder consisting 56% cement, 34% blast furnace slag, and 10-11% ceramic waste. This approach increased the strength and durability of the beams while reducing the carbon footprint in the construction industry. Lam et al[3] Four different ratios (10%, 20%, 30%, and 40% by weight) of CBW, and two samples where CEWA replaced fine aggregate, at 50% and 100% levels. The results obtained from the experiments revealed certain notable findings. Firstly, workability of concrete reduced as a result in these additions. Secondly, compressive strength in the concrete reduced in around 7 days, but exhibited higher values at 28 days and over a longer duration. Additionally, it was observed that utilizing 40% clay brick powder led to an increase in the initial setting time to 65 minutes. Finally, the incorporation of these waste materials led to drastic decrement in drying shrinkage in the sample. Gharibi et al[32]conducted an experimental study aimed at enhancing the mechanical also thermal properties. To achieve this, author utilized ceramic electrical insulator waste as substitute for both fine aggregates, with proportions of 25%, 50%, 75%, and 100%, and the coarse aggregate, with replacement ratios of 50% and 100%. The results obtained from the experiments demonstrated several positive outcomes. Firstly, there was a rise in the concrete's compressive strength, indicating improved structural integrity. Additionally, the concrete exhibited lower water absorption, which is beneficial in terms of durability and resistance to moisture-related issues. One notable finding was the substantial decrease of 41% in thermal conductivity. This reduction in thermal conductivity signifies a significant step towards creating a more sustainable environment and facilitating easier construction practices. Furthermore, a regression analysis was performed to analyze the data and provide guidelines for optimizing thermal conductivity in future applications. Overall, this research contributes to the growth of green practices. Nepomuceno et al [33] Multiple samples prepared through incorporating varying amounts of recycled ceramic waste, ranging from 0% to 75%. Once the samples had hardened, a series of tests including flexural, compressive, and tensile tests were performed to evaluate their properties. The findings revealed that as the quantity of recycled waste raised, also compressive strength exhibited consistent downward drift. Similarly, flexural along with tensile properties followed same pattern. Notably, concrete samples with a 30% replacement of the natural coarse aggregate demonstrated superior mechanical properties compared to the other percentages tested. In summary, the author's experimental study focused on creating sustainable concrete by incorporating RCECA from IBW. Various tests were made on hardened concrete, as the quantity of recycled waste increased, the compressive strength and other mechanical properties generally decreased. However, the concrete samples with a 30% substitute of the NCA exhibited the favorable properties.

DISCUSSIONS/CONCLUSION

A potential direction for eco-friendly building materials Using ceramic waste in concrete to substitute for both fine and coarse aggregates. Beyond this, it has been shown that the addition of metallic and non-metallic fibers significantly improves the characteristics of concrete while successfully reducing problems with early age cracking. An important point is that the ideal volume for fiber insertion in concrete often surpasses 1%, resulting in significant advancements. Waste ceramic aggregates are mostly composed of $SiO2$ (60%–75%) and $Al2O3$ (15%–20%), according to chemical investigations such X-ray diffraction (XRD). Incorporating ceramic aggregates into concrete formulations results in concrete that performs better than conventional concrete in terms of abrasion resistance. However, the modulus of elasticity does decrease when ceramic aggregates are used in place of natural aggregates.

Additionally, compared to conventional concrete combinations, ceramic aggregate concrete tends to show larger shrinkage and lower ultrasonic pulse velocity (UPV) values. A better pore system is created when ceramic powder and fine aggregate are added to the mixture. Enhancing resistance against chloride attack and reducing the extent of chloride infiltration. Which is a significant benefit for the longevity of concrete. Due to the beneficial pozzolanic qualities that the ceramic powder naturally possesses, the addition of ceramic powder further strengthens resistance against sulfate reaction. When using ceramic alternatives in place of traditional aggregates in situations where materials are exposed to high temperatures, damage is reduced.

It's important to keep in mind that the type of ceramic aggregate employed has a complex relationship with the workability of concrete, with variances in water absorption capacity occasionally being seen. The chemical components included in ceramic aggregates, which promote advantageous chemical reactions, are largely responsible for the reported improvements in concrete characteristics.

Ceramic aggregates have a greater capacity to absorb water and have a larger porosity, which results in pH adjustments for the alkali activator and a decrease in the liquid-to-binder ratio, both of which improve the performance of concrete. Fibers also greatly improve the structural integrity of the concrete, increase flexural strength, and significantly reduce fracture breadth, whether they are employed alone or in combination. The achievement of the appropriate levels of mechanical strength and fracture resistance depends heavily on the proper alignment of fibers within the concrete mix.

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