CAPITAL UNIVERSITY OF SCIENCE AND TECHNOLOGY, ISLAMABAD

Combined Effect of Eggshell and Ceramic Waste Powder as Partial Cement Replacement in Wheat Straw Reinforced Concrete

by

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This humble effort is dedicated to

My Parents

For their believe in me

My Brother

For his continous support

My Supervisor

For his guidance and support

CERTIFICATE OF APPROVAL

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Abstract

The increased availability of plant fibres encourages researchers to focus on their possibility as building materials. The structural integrity of concrete reinforced with such plant fibres needs to be investigated. To begin with, wheat straw is chosen among all plant fibres to be researched for its potential use as a building material. Pakistan produces 26 million tonnes of the 731 million tonnes of wheat produced annually worldwide. Utilizing wheat straw in civil engineering applications can be an effective solution owing to its easy accessibility and low cost resulting from its surplus availability in many countries as the end product of wheat crops. On the other hand, production of concrete use cement as prime member, which directly increase the use of natural resources. Continuous use of natural resources leads to pollution and same by cement production in industry. Secondly, waste is being spread on landfills throughout country. Construction activities generate a significant amount of waste, including ceramic materials such as sanitary items and tiles, which are often disposed of in open lands, leading to environmental pollution. One potential solution to reduce this waste is to use waste ceramic powder as a partial replacement for cement in construction materials. Similarly, the egg industry generates a substantial amount of eggshell waste, which can be utilized as a sustainable alternative to cement in concrete production, thereby reducing waste and promoting environmental sustainability. Waste ceramic and eggshells from local vendors are selected for cement replacement in this study. This research idea will help to reduce waste from landfills and will also reduce the quantity of cement in concrete potentially.

Eggshell and waste ceramic powder are used as cement replacement to achieve selected target. Combine effect of eggshell and ceramic waste powder as partial replacement in wheat straw reinforced concrete investigated by making seven type of different mixes which includes PC, WSRC, PC-Ce15, WSRC-Ce15, WSRC-Ce15-ES5, WSRC-Ce15-ES10, and WSRC-Ce15-ES15. Cement is replaced partially at different percentages and effect of hybrid waste materials is explored. Mix design of 1:2:3 is selected with 0.45w/b and 1.5% superplasticizer by weight of binder. Different properties of concrete will be explored in this research including fresh, hard, and micro structural analysis of concrete. Tests performed includes slump, compaction factor, fresh hardened density, water absorption, mass loss, compressive flexural properites, and SEM. WSRC-Ce15-ES10 remained at top in water absorption properties of concrete than all other mixes followed by WSRC-Ce15-ES15. WSRC has showed decrement in compressive strength by approximately 50% and increment of compressive toughness by 137%. Similarly, WSRC-Ce15 showed as compared to PC-Ce15. Using ceramic at 15% cement replacement has increased compressive strength of fiber reinforced concrete but reduced compressive toughness. Eggshell at 15% showed increment in compressive strength as compared to WSRC and WSRCC. Flexural Strength of PC remain at top as compared to all other mixes but, there is remarkable increase of flexural toughness of all other mixes. WSRC-Ce15-ES15 is selected as optimized mix due to its higher strength as compared to all other fiber reinforced mixes. Reduction of cement up to 30% along with slightly improved properties as compared to WSRC mixes approved WSRC-Ce15-ES15 as optimized mix. It can be utilised in many elements of building i.e., copping, screeding, fascia walls, parapets walls, lean, spacers, non-bearing pedestals, and repair work. Treatment of wheat straw along with organic waste as cement replacements needs proper working to further explore the behavior of selected mix.

Keywords: Wheat Straw; Ceramic Waste Powder; Eggshell Powder; Fresh Properties; Mechanical Properties; SEM.

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Abbreviations

Ce	Compressive Energy
Cem	Compressive Energy before Peak
Cep	Compressive Energy after Peak
CTI	Compressive Toughness Index
CWP	Ceramic Waste Powder
ESP	Eggshell Powder
Fe	Flexural Energy
Fem	Flexural Energy before Peak
Fep	Flexural Energy after Peak
FTI	Flexural Toughness Index
MOR	Modulus of Rigidity
PC	Plain Concrete
WS	Wheat Straw
WSRC	Wheat Straw Reinforced Concrete
WSRC-Ce15	WSRC with 15% Ceramic
WSRC-Ce15-ES10	WSRC with 15% Ceramic and 10% Eggshell
WSRC-Ce15-ES15	WSRC with 15% Ceramic and 15% Eggshell
WSRC-Ce15-ES5	WSRC with 15% Ceramic and 5% Eggshell

Chapter 1

Introduction

1.1 Theoretical Background

As the world is progressing very fast in every aspect of life and its needs. With the continuous progress it is leaving great impact on nature. Construction industry is one of largest producing industries of world [1]. Growing population all around the world demands more space and facilities. To fulfill these facilities, we need construction in shape of residential or commercial buildings. Natural resources demand is increasing with the increase in construction. Major constituents being consumed in construction industries are cement, sand, aggregate, steel, and wood [2]. All these constituents are natural produce being extracted continuously to fulfill demands. Cement being most important material in construction industry as binding material is in high demand. To produce cement, mountains are being demolished and then factories after processing produce a lot of cement [3]. Even factories running produce a lot of pollution by burning fuel which in turn effects air quality. Every constituent of construction industry needs to be replaced and most importantly cement needs replacement. Large amounts of household waste can be converted into alternative resources that can be used to address environmental issues, sustain energy needs, and reduce the need for landfill space. Ceramic is one of these materials. Broken parts from ceramic industries are considered as ceramic waste. This waste can be grinded to powder form by many ways. The usage of ceramic waste powder (CWP) as cement replacement will have a positive effect on the environment [4]. The ceramic industry produces 15 to 30 percent of the overall production waste [5]. Currently, there is no recycling of this trash in any way. Contrary to it, ceramic waste is durable, robust, and resistant to physical, chemical, and biological pressures. Ceramic industries are under pressure to find a solution for the disposal of their waste as it accumulates every day.

Additionally, studies have been conducted on using agricultural wastes as a replacement for cement and fine aggregate [6]. For instance, substitutes for cement and fine aggregate have included rice husk ash, sugar cane bagasse ash, sawdust ash, etc. Utilizing agricultural wastes offers various benefits over using industrial outputs, including being widely available, inexpensive, low density, recyclable, energy-efficient, and environmentally friendly [6]. Eggshells, the egg's tough external shell, are an example of a sort of agricultural waste. Chambers within the eggshell make up about 10percent of the egg's weight. Over 8 million tons of eggshell trash are thought to be produced each year by the world's steadily growing egg industry. Even though eggshells can be used for a variety of purposes, such as the creation of calcium phosphate ceramics, as a source of biodiesel, as an adsorbent to remove ionic pollutants, and as fertilizer, a sizable number of eggshells are still thrown away. Eggshells contain a substantial amount of calcium carbonate (CaCO_3), which is required for the formation of the binder gel (calcium-silicate-hydrate [C-S-H]) in cementitious materials [6]. Therefore, it can be used as a powdered substitute for cement and fine aggregate in construction products. Other than cement replacement in concrete natural fibers can be added to enhance the properties of concrete. Researchers have used natural fibers as useable alternative to steel fiber or some artificial fibers in concrete. Coir, sisal, sugarcane, banana, bamboo, malva, date, vakka, kenaf bast, jute, palm, hemp, pineapple leaf, flax, ramie bast, abbaca leaf, hibiscus cannabinus, and sansevieria leaf are some of the natural fibers utilized in civil engineering [7].

Natural fibers can contribute to long-term development in a sustainable way [8]. Natural fibers are inexpensive and readily available in many nations. Due to which, when equated to the entire cost of composite, fiber use as material for construction costs extremely less, virtually negligible. Natural fibers can help you save a lot of money in this way. Natural fibers may also be easier to handle due to their elasticity, which is a benefit of natural fibers over artificial fibers [9]. However, many academics continue to be interested in the endurance of natural fibers. However, many experts are still interested in the long-term durability of natural fibers. As a result, after subjecting it to various climatic and ageing conditions, the endurance of natural fibers in concrete was assessed experimentally. Wheat straw is selected to be used in concrete and observe its properties. In this study and experimental work, focus is on reducing the quantity of cement along with addition of natural fiber. Concrete with replacement of cement with ceramic waste powder will be considered as plain concrete. Eggshell powder will replace cement in plain concrete. Natural fiber addition will also be observed to enhance toughness properties of plain concrete. Similarly, eggshell powder will be added in wheat straw reinforced concrete as cement replacement. Kalakada et al. [10] replaced cement up to 30percent and produced good results. Nalli and Vysyraju [11] replaced cement with ceramic at 15percent, which results in good strength. Vempatala et al. [12] replaced cement with two different materials at different percentages, their results showed improved strength at 28 days (25CWP and 15GGBS). There are many other research and experimental other than above mentioned in which cement was replaced at higher percentages. It is observed that even up to 40percent replacement of cement has also come out with enough binding properties required for concrete. However, in this study cement will be replaced up to 30percent to produce improved quality concrete. In this research focus is on reducing cement content along with improvement in properties of concrete including water absorption, density, compressive strength, toughness properties, and permeability. Eco-friendly fiber reinforced concrete with other benefits will be result of this research as cement content will be reduced by hybrid waste replacement.

1.2 Research Motivation and Problem Statement

The world is moving toward sustainable approach in every aspect of life. Cement production leads to CO_2 emissions which directly affect the quality of life. Natural resource consumption is also increasing with the increase in concrete production. Surface cracking in concrete leads to greater issues as it results in water seepage and environmental attacks. Concrete is a main part of the construction industry which can't be deducted as it provide base for every structure. Replacement of cement along with addition of fibers is very much needed to enhance concrete properties and to reduce adverse effects of environment. Clean and green environment leads to healthy life for all living organisms. So, replacements of concrete constituents are done to reduce cement and fibers are added to enhance properties of concrete i.e., surface cracking and brittle nature. Thus, the problem statement of research work is given below as:

"*The production of cement is one of the major causes of environmental disturbance throughout the country. The only solution to this disruption is to replace the cement with a less damaging material. Secondly, disposing of eggshell and ceramic waste is leading towards destruction of the environment, which is directly destroying the quality of life. Using this waste to replace cement can help in the production of eco-friendly concrete. The abundance of wheat straw produced can also be consumed to improve the properties of concrete i.e., brittleness and surface cracking. The combined effect of eggshell powder, ceramic powder, and wheat straw is completely unknown. With the progress of the world, conventional concrete needs to be evaluated to overcome its shortcomings. The properties of concrete, along with environmental issues, need improvement.*"

1.3 Overall Objective and Specific Aim

The overall objective of this research is to provide sustainable materials for concrete production that can minimize cement use while focusing on sustainable development and to improve behavior of concrete. Reduced use of cement can help to reduce pollution and its negative effects on living beings. Reducing cement use can also save natural resources from the regular extraction of raw materials for cement. Utilization of natural fibers is critical in improving the behavior of concrete. Therefore, it is necessary to reduce cement use in concrete along with natural fiber reinforcement.

However the specific aim is to explore the combined effect of eggshell and ceramic waste powder as partial cement replacement in wheat straw reinforced concrete.

1.4 Scope of Work and Study Limitations

The scope of work includes identification of problems in concrete and also those which are associated with continuous cement use in concrete making and its adverse effect on environment. Natural fibers utilization helps to improve properties of concrete while waste materials as partial replacement of cement in concrete making not only reduce cement consumption and problems associated with it but also help to reduce waste spread in open lands along with improved properties i.e., strength, toughness, and surface cracking. This idea can help in economic development by producing re-useable waste material in concrete making and improve concrete properties. The mix design selected for this work is 1:2:3 with 0.45 w/b and 1.5% S.P by weight of binder. Wheat straw is added by volume of wet concrete i.e., 1%, Athloey et al., [13] added PPF by volume. Mechanical properties of all mixes will be determined accordingly. Samples for each test are made of wheat straw reinforced concrete with cement replaced by eggshell and ceramic waste powder in the lab. For water absorption, mass loss, densities, SEM, and compressive strength cylinders of size (102 mm x 204 mm) will be made. Prisms of size (102 mm x 102 mm x 457 mm) will be made for flexural strength. Mixes include PC, WSRC, PC-Ce15, WSRC-Ce15, WSRC-Ce15-ES5, WSRC-Ce15-ES10, and WSRC-Ce15-ES15. Separate molds are cast for water absorption and mass loss tests, which are exposed to heat at high temperature. An average of two samples will be taken for compressive testing and three for flexural testing for each mix. Curing time is 28 days for all samples. Curing is done in water tank with normal atmospheric temperature. Size and use of each sample is mentioned in Table 1.1 in detail. Table 1.1 shows name and constitution of mixes along with batching ratio and tests. In this study properties of concrete limited to materials

of selected area and industry. Eggshell and ceramic waste needs to be treated for best use in concrete. Separate industry or workplace is required to convert both wastes into use able form at large scales for practical purposes. Wheat straw is obtained directly from local markets. Mechanical properties ,fresh and hard properties, SEM analysis are part of this experimental work.

Table 1.1: Scope of Work

Sample	Mix Design							
Description	Batching Ratio	PC Cement 100%	WSRC Cement 100% W.S 1%	PC-Ce15 Cement 85% Ceramic 15%	WSRC-Ce15 Cement 85% Ceramic 15% W.S 1%	WSRC-Ce15 -ES5 Cement 80% Ceramic 15% Eggshell 5%	WSRC-Ce15 -ES10 Cement 75% Ceramic 15% Eggshell 10%	WSRC-Ce15 -ES15 Cement 70% Ceramic 15% Eggshell 15%
Cylinders D = 102 mm H= 204 mm	1:2:3 w/b = 0.45	Water Absorption, Mass Loss Compressive Strength, Cem, Cep, CTI, & SEM						
Beams H & W = 102 mm L = 204 mm	S.P. 1.5% by weight of binder	Flexural Strength Fem, Fep, & FTI						

Note: Wheat Straw is Added by Volume of Wet Concrete.

1.5 Methodology

Opted methodology for this research work is shown in Figure 1.1. Use of ESP and CWP in concrete and adverse effect of cement use in concrete making is studied from previous research. Wheat straw reinforced concrete will be made using cement with partial replacement by ESP and CWP . Results of all mixes will be compared, and best mix will be recommended for future studies and real-life implementation. Tests include fresh, absorption, compressive, and flexural properties and SEM analysis.

FIGURE 1.1: Opted Methodology

1.6 Novelty of Work, Research Significance and Practical Implementations

To the best of author's knowledge, no research work has been conducted on combine effect of ceramic waste, eggshell powder, and wheat straw in concrete. Thus, the current study is aimed to study the mechanical, and absorption properties of wheat straw reinforced concrete using ceramic waste eggshell powder as cement replacement.

Construction industry has a significant impact on environmental pollution. It is the need of time to search new building material with properties to overcome the issues related to material waste in construction industry [14]. Replacement to cement or other ingredients by waste materials can help in reduction of pollution caused by construction industry and there spread on landfills. This replacement will help in production of eco-friendly concrete for the use in civil engineering and construction industry. Replacement of cement with waste materials such as ceramic and eggshell helps to reduce adverse effect on environment and to enhance properties of concrete [15–17].Technically speaking, sustainable building is a developing force in the construction sector that aims to reduce the negative effects of the business on the environment, such as global warming, environmental deterioration, and resource depletion [18]. Using natural fibers as disperse reinforcement in concrete are used to enhance its post cracking behavior [19–21]. The multi-level cracking in concrete can be controlled by utilizing same or two different types of fibers with different length, size, proportions and properties [22]. This research will help to explore the idea of utilizing different waste materials altogether in fiber reinforced concrete. Utilization of fiber and waste materials will help to enhance concrete behavior along with reduction in negative impact of construction industry on environment.

Construction industry is one of the biggest industries in the world, as it provides base for every other field. Sustainable construction becomes the need of present day. The construction industry is growing rapidly with increase in population. To accommodate increasing population, it is compulsory to build structures including buildings, roads, and dams. Main constituents being used in construction industry are aggregates, sand, and cements. Continuous use of natural products is increasing too many issues around the globe. The construction industry is contributing a lot to world GDP i.e., 13%. Construction industry is growing and contributing a lot to GDP and making much easiness to people all around the world. In addition, the construction sector accounts for 39% of all carbon dioxide (CO_2) emissions and 36% of all global energy use [23]. This research provided replacement of cement with waste materials. Concrete resulted as by product of this research can be used in many applications of construction industry. Building, bridges, and roads consist of many small elements which are hardly taking any load as compared to complete structure. Concrete of these elements can be replaced with resulted concrete. Copping, screeding, fascia walls, parapet walls, repair work, lean, spacers, and pedestals. All these elements in construction can be made with lower strength concrete. Wheat straw reinforced concrete with 15% ceramic and 15% eggshell powder can be used for all these elements. This can help to reduce use of cement at initial stages for betterment of society and can save budget. It can also help to minimize emission of CO_2, by replacing the cement content in fiber reinforced concrete and to reduce adverse effects of concrete to the environment. Concrete produced by using the concept of this study will decrease the weight of concrete and reduction of cement, which can be applicable in real life project up to some extent.

1.7 Thesis Outline

Five chapters make up this research project. The experimental work described in this thesis can be broadly divided into two categories: (i) Material characterization, or the optimization of an eggshell and ceramic powder fibre reinforced concrete mix; and (ii) the structural performance of a hybrid waste powder cement replacement for fibre reinforced concrete. As a result, the thesis is established in the steps outlined below.

Chapter 1:Introduction, problem statement, overall objective, particular target, research methods, and thesis outline are all included in this chapter.

Chapter 2: This chapter includes a review regarding the flaws of concrete and the governing parameters in performance consideration and remedial measures of these flaws according to literature. The incorporation of hybrid waste materials in discrete form in concrete for enhancing the structural performance, is also presented considering various research. Narrowing down the materials list, usage of natural fibers (wheat straw) for enhancing flexural performance of concrete is also discussed.

Chapter 3: This chapter consists of the experimental methodology. This chapter explains the background, materials used, and optimization procedure of mix design, the procedure of casting and parameters to be considered for optimized mix design.

Chapter 4: Results and Analysis of mechanical properties and microstructural analysis i.e., SEM are also discussed.

Chapter 5: Discussion and Practical Implementation of optimized mixes.

Chapter 6: Conclusion and future recommendations are mentioned in this chapter.

Chapter 2

Literature Review

2.1 Background

In old time fibers have been used to enlarge concrete behavior, performance, and mechanical properties [24]. Wheat straw is the most common natural fiber in our country[25]. As it is locally available and has impact in concrete in terms of toughness and durability, it can be used in good terms for construction industry. Natural fibres' advantage over synthetic fibres may also include how simple it is to handle them because of their elasticity [26]. However, many experts continue to be interested in the durability of natural fibres [27–30]. Accordingly, after being exposed to various climatic and ageing circumstances, the endurance of natural fibres in concrete was assessed experimentally. Cement is the main component of concrete as it provides binding properties, but it has great impact on society [31]. There is need to reduce cement use in this industry to produce ecofriendly living. Cement can be replaced with many materials but to get another benefit we can replace cement with waste materials. Ceramic contributes a lot to building industry in terms of tiles, bricks, and sanitary items [32]. During application there is many wastage observed on construction sites. To avoid waste dumps and cement use ceramic can be used as cement replacement in powder form. Many other materials can waste cement from our daily life usage i.e., eggshells, available in abundance in loacal markets openly. Egg shells can also replace cement in powder form with many benefits [33]. Combine effect of ceramic and eggshell in wheat straw reinforced concrete is yet to be determined.

2.2 Identification of Concrete Flaws and Possible Remedial Measures

Concrete being used widely throughout world may have many benefits above other construction elements but on the other hand it poses many flaws [34]. In addition to flaws concrete also becoming dangerous to environment due to its component's extraction. Construction industry face many issues in terms of concrete flaws [35]. As concrete is good in compression but lacks in tensile and flexural behavior. To tackle these flaws of concrete we provide steel in greater quantity. There are many additives which can enhance such properties of concrete. Increasing these properties can decrease the steel in concrete which can directly reduce the cost of concrete. Fiber addition can increase the flexural properties of concrete by binding different component of concrete together [36].

2.2.1 Flaws

There are many flaws in concrete including brittleness and its composition [37]. Microcracks which are developed during the process of hardening of concrete makes the composite weak [38]. Surface cracks in concrete results in seepage of water which results in corrosion of steel. Concrete is brittle materials which results in early breakdown if load applied to it. In the modern construction business, concrete is the most often utilised material. Approximately half of the 4 billion tonnes of cement produced worldwide is used to make concrete for construction purposes [39]. Due to its many benefits, including its affordability, durability, resistance to fire and water, and many others, cement is the most common building material. However, concrete's detrimental effects on the environment are becoming more widely recognised. Cement production is one of the leading sources of greenhouse gases. With 900 kg of CO_2 released into the sky for every tonne of cement produced, industry is responsible for around 7% of all worldwide CO_2 emissions[40].

In addition to producing a significant amount of greenhouse gases, the cement industry releases significant amounts of particulate matter (PM), nitrogen oxides (NO_x), carbon monoxide (CO), sulphur dioxide (SO_2), and volatile organic compounds[41]. Concrete consists of many raw materials which are extracted from natural resources and create problem for nature. In addition to this considering concrete to be casted there are many flaws even then. Components of cement are also damage to environment separately in extraction and making. CO_2 emissions during cement production creates greater risk to environment. Even during extraction of raw materials for cement production many mountains were damaged. Remedy to above mentioned flaws because of concrete is much needed.

2.2.2 Possible Remedies

Remedies are to solve the issue in any case. According to flaws mentioned above, remedy to use of cement is to replace cement with materials which are not harmful in production or by product of any other industry. Fiber addition to concrete can resist surface cracking in concrete which are to be used in this research program, also fiber addition can make concrete ductile which is quite improvement in concrete properties [42–45]. Microcracks which is one of internal flaw of concrete can be healed by adding fibers [38]. Including fiber can reduce quantity of other ingredients of concrete which is directly reducing the use of natural resources. Introducing Reduce-Reuse-Recycle phenomenon in this industry has extensive results in reducing the hazards of pollution. The use of replacement materials offers cost education, energy savings, arguably superior products, and minimize the hazards in the environment. Usage of recycled products also changes the composition by participating in the hydraulic reactions [46]. Concrete made with ceramic waste powder (CWP) as an alternative element which will be better for the environment [47–50]. This study's objective was to describe the CWP's composition, morphology, and activity. Additionally, the study assessed how well fresh and cured concrete performed when CWP was used as an alternate ingredient to partially replace cement and how it react with other waste materials [51]. Similarly, replacing eggshell powder with cement will also help to reduce flaws generated by concrete [52–55]. Replacement of cement is only remedy to all flaws generated and incorporated during the production of cement.

2.3 Waste Materials as Cement Replacement

The use of solid waste in valuable products becomes a worthwhile deal for individuals, organizations and countries themselves [56]. Solid waste dumps will continue to receive large amounts of waste due to the world population's rapid growth and in order to satisfy consumer wants. Large-scale solid waste conversion into an alternate material will assist address environmental and landfill overflow issues while minimising the need for natural resource of materials and energy. Numerous studies have focused on the use of solid waste materials in concrete, a common building material, especially those that can substitute cement, a major source of greenhouse gas emissions worldwide [51]. As seen in the studies carried out concerning the replacement of cement with fine aggregates in mortars, this is a theme of vast interest, from the environmental, technological-functional and economic points of view [57].

Researchers have replaced sand with eggshells [58]. The experimental findings have demonstrated that there is a positive correlation between the level of replacement and the resulting strength of the composite material. This suggests that eggshells have contributed to the overall strength of the composite, even when used as a replacement for sand. Additionally, it appears that the eggshells have improved the binding properties of the composite material, as evidenced by the increased strength values. Razali et al., [58] stated that presence of CaO in eggshells enhanced concrete properties even as sand replacement. Sand is an inert material that provides sufficient workability to concrete. If sand is replaced with a non-inert material, it may react with other ingredients in either a positive or negative way. The presence of Cao, $\mathrm{Si}O_2$, and $\mathrm{F}e_2O_3$ in ESP [59] and OPC [59] presents eggshells as potential replacements to cement, as shown in Table 2.1. For eggshells to replace cement, it is essential that the fineness of the eggshell powder is similar to that of cement. This would ensure proper mixing and incorporation of the eggshell powder into the cement matrix, resulting in a more homogenous and durable material. In order for eggshell powder to fully react with cement, it requires a maximum surface area. Raw eggshells or larger eggshell fragments possess a lower surface area, which limits their ability to react with water and exhibit binding properties. However, when the eggshells are ground into powder form, they provide a higher surface area for reaction with water as cement, resulting in improved binding properties. In this study cement is replaced with different waste materials and for that purpose eggshell [60–62] and ceramic waste [63, 64] are selected for partial cement replacement. Replacement of cement is done to achieve sustainable construction and pollution free environment.

2.3.1 Ceramic Waste as Cement Replacement

Concrete is the most widely used man-made substance on the planet, and it has sparked considerable interest as a means of recycling solid wastes [65]. Concerns about environmental contamination as a result of environmental restrictions drive additional research into the use of pozzolanic materials derived from industrial waste such as ceramic waste, fly ash, and silica fume [66]. Partially replacing cement with waste materials like fly ash, silica fume, or ceramic might help with landfill issues while also improving the durability, workability, and strength of concrete [67]. The chemical, physical, and mineralogical characteristics of the ceramic waste and their effect on the properties of mortar are explained by previous researchers such as [66]. Samadi et al. [68] focuses on waste product recycling and reuse to create new construction materials. Cement was replaced with ceramic waste because of the high demand for conventional concrete. The penetration and a few durability components of concrete that substituted ceramic waste powder for cement were examined in studies, and it was discovered that the substitution helped to lower permeability and increase measured durability [51]. According to estimates, up to 10% to 30% of ceramic production overall is wasted [69]. Kannan et al. [70] stated that 20 to 40% of the cementitious materials in the mix might be replaced with CWP to create high-performance concrete. The newly made concrete will have diminished strength properties at a young age and comparable strength properties at a later age when matched to benchmark conventional concrete without CWP. Mousavi at al. [71] replaced cement with 40% tiles ceramic

Table 2.1: Chemical Composition of Ordianry Portland Cement, Ceramic Waste Powder, and Eggshell Powder by Different Researchers

Composition	OPC		CWP		ESP		
Name	Dieb & Kanaan [39]	Yu et. al. [59]	Dieb & Kanaan [39]	Devi & Venkateswarlu [72]	Yerramala [68]	Balamurugan & Santhosh [73]	Yu et. al. [59]
CaO	61.5	60.1	1.7	4.46	52.15	47.49	52.10
SiO2	21.0	21.8	68.6	63.29	1.22	-	0.58
Al2O3	6.1	6.6	17	18.29	0.28	0.11	0.06
MgO	3.8	2.1	2.5	0.72	0.60	-	0.06
Fe2O3	3.0	4.1	0.8	4.32	0.16	-	0.02
SO3	2.5	2.2	0.12	0.1	-	0.38	0.62
Na2O	0.59	0.4	-	0.75	-	0.14	0.15
LOI	1.6	2.4	1.78	1.61	-	-	45.52
IR	0.9	-	-	-	-	-	-

waste and produced improved results. Utilizing ceramic wastes not just helps to save landfill space and preserve the environment from any contamination effects, but also assists to get it used in mortar and other building material [74]. Table 2.1 shows chemical composition of CWP.

2.3.2 Eggshell Powder as Cement Replacement

A poultry waste with a chemical characteristics nearly identical to that of limestone is calcium-rich eggshell [59]. Utilizing eggshell waste in place of natural lime to replace cement in concrete can reduce the amount of cement used, preserve natural lime, and reduce waste. According to a study, the annual production of eggshell trash is 190000, 150000, and 11000 tonnes in India, the United States, and the United Kingdom, respectively [59]. Eggshell waste has a variety of uses, including as fertiliser as a component of animal feed. The majority of the eggshell trash, however, is dumped in landfills. Due to the connected membrane, eggshell trash in landfills attracts vermin and creates issues for the environment and human health. There haven't been many studies on using eggshell waste in civil engineering applications [59]. Environmental issues concerning the disposal of eggshell waste as well as the excessive use of cement/aggregate are reduced by the use of ESP in the production of construction materials [6]. Numerous studies have been conducted regarding the use of eggshell powder as a cement/fine aggregate alternative in cementitious materials. Mammillary, calcareous, and cuticle are the three layers that make up eggshell, an inorganic substance. Approximately 94% of the weight of eggshells is made up of CaCO_3 , following organic matter (almost 4%), $Ca_3(PO_4)^2$, and MgCO_3 [6]. The major component in the composition of ESP is CaO, which ranges from 32.5 to 99.8% [72]. The mechanical behavior of cementitious materials is positively impacted by the greater CaO content of the ESP [72], while lower CaO content deteriorates the performance of the composite [73]. From 2.5 to 10% of the researchers substituted cement with eggshell powder [75]. This substitution performed well in terms of strength [75]. Comparing the experimental sample to the control sample, it was shown that fractional cement replacement utilising ESP was effective in achieving increased strength [76]. Table 2.1 shows chemical composition of ESP.

2.4 Fiber Reinforced Concrete

According to AC1 116R, Cement and Concrete Terminology, fiber-reinforced concrete (FRC) is simply concrete with scattered randomly arranged fibers. The present period of fiber-reinforced concrete research and development has been underway for more than 30 years [77]. Thousands of research publications on the topic have been published in the following three decades. Numerous people have completed the requirements for academic degrees at all levels, including bachelor's, master's, and doctoral degrees, while also conducting research and making contributions to the development of FRC [77]. There is still a strong level of interest in FRC development, as seen by the amount of local seminars, regional symposia, and worldwide conferences that are still organised every year and around the world. Such educational initiatives promote knowledge of FRC as a building material while also translating the results of research into the business world. Fiber-reinforced concrete (FRC) has drawn a lot of attention in recent years in the field of civil engineering, primarily because it strengthens concrete's weak tensile properties and shrinkage cracks. The FRC research findings still have a lot of issues, though. For instance, there are still disagreements on the positive or negative effects of different types of fibres in concrete on performance. There are disagreements over the degree to which each fiber's size, strength, elastic modulus, and other distinguishing characteristics have an impact on the characteristics of the substrate [78]. Many issues related to fibers are still not solved i.e., treatment of fibers, sizes, quantity and displacing positions. For a very long time, fibres have been used to produce construction materials [79]. Initial research and testing has shown that adding natural and synthetic fibres can produce astonishing results since they have a significant positive impact on the composite material's mechanical qualities. Compared to conventional reinforcing bars, natural fibre reinforcement offers far greater energy and economic benefits since the amount of fibre required is much lower in natural fibre reinforcement [79]. The potential of natural and synthetic fibres as reinforcement in construction materials, primarily concrete, has recently come under investigation specially natural fibers due to their abundance and lower cost as compared to synthetic and steel fibers. Fibers posses many benefits over ordinary reinforcement if properly used in concrete.

2.4.1 Natural Fibers Reinforced Concrete

Natural fibers have been utilized as useable alternative to steel fiber or some artificial fibers in concrete for a variety of uses [80]. Natural fibers play vital role in increasing physical properties of concrete. Natural fibers are of many types throughout the world. These are extracted from trees, crops, living things, and plants. Materials like jute, sisal, coir, rice husk, flax, bamboo, banana, oil palm, sugarcane bagasse and so on, however specialists and researcher have found an alternate kinds in concrete [81]. Although natural fibres are less expensive than standard reinforced concrete, they take more skill to produce, place, and mix them, and their long-term performance and durability remain unknown [82]. The most popular building material on Earth is concrete, which has a high compressive strength but a low tensile strength. In order to overcome this drawback, normal concrete and steel reinforcing bars must be used in tandem. This results in a material with strong compressive and tensile strengths but also with a lengthy post-crack deformation (strain softening). Unfortunately, reinforced concrete has a high level of permeability that makes it susceptible to attack from chloride ions and water as well as other corrosive substances. The primary cause of infrastructure deterioration is really steel rebar corrosion[83, 84]. Since 200 kg of steel rebar are typically used for every cubic metre of concrete, switching to vegetable fibres as rebar is a significant step towards building structures that are more environmentally friendly. Reinforced steel, on the other hand, is an expensive material that uses a lot of energy and is made from non-renewable resources. Therefore, encouraging the use of natural fiber-reinforced concrete could be a solution to increase concrete durability and environmentally friendly building practices [85].

2.4.2 Wheat Straw Reinforced Concrete

Wheat straw is a byproduct of the wheat crop and is frequently more than what is needed in many nations. Therefore, using wheat straw in applications of civil engineering will be successful because it is inexpensively available and simple to access [86]. Numerous researchers have already used wheat straw as a distributed

Table 2.2: Behavior of Wheat Straw Incorporated Mixes by Different Researchers

Wheat Straw Reinforced Concrete Application	Matrix	Fiber Reinforced Concrete Properties	Obtained Values	Refrence
Building Material	Cement Concrete	Compressive Strength	31.7 MPa	Merta & Teschegg [23]
		Notch Tensile Strength	3.3-3.7 Mpa	
		Fracture Energy	111-137 MPa	
	Cement Mortar	Maximum Bending Load	2.4-2.9 MPa	Albahattiti et. Al. [87]
Ground Floor Slab	Concrete	Residual Tensile Strength	1.88 MPa	Nepal [88]
Rigid Pavement	PCC	Compressive Strength	1.3-1.7 Mpa	Farooqi and Ali [89]

reinforcement and straw bales, respectively, for structural components and concrete composites. Ashour et al. [90] stated that straw bales' compressive strength had increased. Merta et al. [91] studied the strength of elephant grass, hemp, and wheat straw reinforced concrete. When compared to plain concrete, the fracture energy of optimal hemp, wheat straw, and elephant grass reinforced concrete increased by 70%, 2%, and 5%, respectively. Albahttiti et al. [92] also looked at cement mortar with wheat straw reinforcement. We have investigated the flexural and compressive properties of cement mortar reinforced with wheat straw. In comparison to plain cement mortar, the stiffness of the examined matrix with a volumetric straw content of 0.75% increased by 23%. Accordingly, wheat straw can be employed as distributed reinforcement in cement concrete composites for a variety of civil engineering structural and non-structural applications, according to studies on wheat straw reinforced composites [93]. Table 2.2 shows properties of wheat straw reinforced concrete.

2.5 Summary

An extensive literature has been reviewed to dig-out the flaws of concrete at structural regarding its brittle nature. Also investigated are the controlling criteria for these faults and potential corrective actions. Early-age distresses are more likely due to cement concrete's traditional brittle nature [94]. Typically, steel reinforcing is utilised to address this problem. Because of this, building construction is extraordinarily expensive. As a result, its excessive use in underdeveloped nations is limited. Early-age microcracking and steel corrosion are the main issues [95]. Natural fibres can, however, be added to cement concrete to reduce cracks and increase structural strength. According to the literature, researchers are concentrating on reducing the amount of biodegradable materials in order to reduce waste in order to move towards sustainable development [96]. As a result, experts from all over the world are becoming more interested in using natural fibres, such as plant and agricultural waste [97]. According to previous research, the load carrying capacities and post-cracking behaviours of concrete reinforced with natural fibres are equivalent to those of concrete reinforced with synthetic fibres. Among all natural fibers, wheat straw is slightly explored yet for concrete composites.

Using waste materials as cement replacement also helps to reduce cement content in concrete which directly reduce the use of natural resources[98]. Two different type of waste materials are selected for this research which will replace cement in different percentages. Preparation of waste materials and fibers is defined in chapter 3. Production of sustainable construction is prime need of modern world, as population is increasing day by day, which is increasing requirement of buildings. Raw materials for concrete are mentioned in chapter 3 for further evaluation.

Chapter 3

Experimental Methodology

3.1 Background

Replacement of cement is discussed earlier to improve environmental condition. Eggshell waste and ceramic are selected to replace cement partially. Wheat straw is also selected to increase toughness of concrete and to reduce steel as it helps to hold concrete for longer period making it ductile. Cement is replaced partially by different percentages. Replacing concrete is observed beneficial to environment and natural resources. In this regard research is performed to reduce cement and produce good quality concrete with better results.

3.2 Raw Materials of Concrete

Raw materials of concrete needs to be discussed to evaluate its elements and their replacements. Concrete is usually made from cement, sand, and aggregate. Water is added to activate cement in binding cause. In this research program raw materials are increased by ceramic waste powder, eggshell powder, wheat straw fibers, and super plasticizer. Increasing materials might affect properties of concrete, therefore materials with good results in previous research were selected.

3.2.1 Cement

Cement is one of the main components of concrete. Cement is of many types according to process in its making. OPC cement was used in this research of Fauji Cement which is purchased locally. It is extremely resistant to breaking and shrinking, but less so to chemical attacks. OPC's initial setting time is quicker than PPC's, hence it is advised for projects where props will be taken down early. OPC cures faster than PPC, which lowers the cost of cure. Therefore, where the cost of cure is prohibitive, suggested. The production of OPC from Fauji cements is as per EN 1971: 2011-CEM I 425N i.e., having 28 days strength of 52 $\pm$ 3 MPa. All these properties are mentioned by the manufacturer. However, chemical composition of cement is given in Table 2.1.

3.2.2 Fine Aggregate

Fine aggregate plays a crucial role in the production of high-quality concrete. It enhances the workability of concrete mixtures by promoting uniformity, reducing the consumption of cement and water, and improving the mechanical strength of the final product. Moreover, it helps to harden the cement paste around the coarse aggregate particles and reduces the potential for segregation during transportation. Fine aggregate also helps to reduce the shrinkage of binding material and fills the voids present in the coarse aggregate, which increases the density of the concrete. Another important function of fine aggregate is that it prevents the development of cracks in concrete by improving its overall strength and durability. In this study, sand obtained from Lawrencepur has been used as fine aggregate, which passed through a 4.75 mm sieve size and retained in sieve number #100. This sand has been carefully selected based on its particle size distribution and other relevant properties to ensure high-quality concrete production. It is worth noting that the quality and properties of the fine aggregate used in concrete production can have a significant impact on the final product. Using appropriate fine aggregate not only benefits the quality of concrete, but can also minimize the environmental impact of production by reducing resource consumption.

3.2.3 Coarse Aggregate

Aggregates are added in concrete to gain strength. Locally available aggregates are collected in different sizes. Aggregates passing from 25mm and retained on 9.75mm are separated from bulk. These aggregates are then washed thoroughly in mixer to remove impurities and dust. After washing aggregates are air dried properly and used in concrete making. Figure shows 3.1 washing procedure of aggregates.

(a) (b)

FIGURE 3.1: Aggregates Cleaning (a) Washing (b) Air drying

3.2.4 Water

Potable tap water is used in the preparation of Specimen. It has pH 6.5-8.5.No impurity or suspended particle in it is observed.

3.2.5 Wheat Straw

Wheat straw fibers are the byproduct of wheat crop which is produced during extraction of seeds from the crop. These are available locally in bulk quantity throughout the country. Locally obtained wheat straw, ranging in length from 15 to 20 mm as measured on randomly selected fibers, is collected, and subjected to a treatment to remove any dust or other contaminants using water. Treatment process involves soaking locally obtainable wheat straw in water for a duration of 15 to 20 minutes, with the aim of eliminating any impurities, dust particles or wax present on the surface of the straw. Following the soaking process, the straw fibers are taken out of the water and left to dry naturally in the air, also done by Farooqi and Ali [99]. Figure 3.4 shows wheat straw obtained from local market.

FIGURE 3.2: Wheat Straw

3.2.6 Ceramic Waste Powder

Ceramic powder is one of the materials which is selected for cement replacement. RAK ceramic waste tiles are acquired from a construction site and are subjected to a thorough cleaning process to eliminate any extraneous particulates or impurities. Cleaning is done by using a normal brush manually. Subsequently, the cleaned waste tiles are subjected to a ball milling process, also reported by Torgal and Jalali [100] , wherein metal balls are utilized within a Los Angeles abrasion machine to achieve the requisite degree of fineness. Ceramic tiles are placed in LA Abrasion drum along with metal balls, which is rotated to crush tiles to powder form. Jaw crusher [101] and hammer mill [102] can also be used to achieve the required powder. Due to availability of metal balls, this process is selected above others. By product is then sieved from 200 number sieve and collected as fine powder as cement. Figure 3.2 shows the phases of ceramic from site waste to powder form.

Figure 3.2 CWP processing, a) waste ceramic spread on open land, b) the process of crushing ceramic tiles in powder form, and c) final fine form of ceramic waste.

a) Waste Ceramic b) Crushing c) Fine Powder

FIGURE 3.3: Ceramic Waste Powder Processing

3.2.7 Egg Shell Powder

Raw eggshell goes through a certain process before it can be used to replace cement. First, the eggshells are cleaned with normal water. Aside from cleaning the eggshell from impurity, this process also removes the thin membrane of the eggshell. After cleaning, the eggshells are dried.Similar process was also reported by Chong et al., [103]. After this the eggshells are initially crushed manually and then subjected to further processing using a blender. To attain the necessary degree of granularity, a mechanical grinder is utilized. The same process was also adopted by Jhatial et al.,[62], Tan et al., [104], and Yerramala [105]. By product is then sieved from 200 and collected as fine powder as cement. Figure 3.3 shows the phases of eggshell processing. To note, proper preparation of cement

a) Washed Eggshell b) Crushing c) Fine Powder

FIGURE 3.4: Eggshell Powder Processing

replacements and treatment of wheat straw is necessary for its use in combination with cement replacements. Cement is partially replaced with eggshell and ceramic waste powder. One is organic waste and the other one is industrial waste; both can react chemically if not treated properly. For wheat straw to be used with cement replacements it is necessary to ensure proper preparation of replacements and treatment of wheat straw. Cement is partially replaced with eggshell and ceramic waste powder. One is organic waste and the other one is industrial waste; both can react chemically if not treated properly. For wheat straw to be compatible with eggshells as both are organic by products, it needs to be cleaned for excessive organic matter so that it doesn't react with any replacements of cement. Other treatments can be adopted for wheat straw to be compatible with replacements in concrete. Composition wise eggshell possess same elements as cement i.e., CaO, SiO_2, AL_2O_3, MgO, Fe_2O_3, SO_3, and Na_2O [59]. As all of these components in cement have yielded acceptable results, they have been utilized in the production of natural fiber reinforced concrete, specifically wheat straw reinforced concrete [99]. Eggshells have been shown to have a similar chemical composition to cement, as demonstrated by various researchers in Table 2.1. Therefore, if cement does not have any adverse effects on the performance of wheat straw fibers, it can be expected that eggshells would also have a positive influence on their behavior in concrete. Partial replacement of cement with eggshell powder improved the reaction between silica from the cement and calcium oxide from the eggshell powder, a byproduct of the cement hydration process in the continuous presence of moisture leading to the formation of the secondary C–S–H gel [104]. Any excessive compound can make them react if not cleaned properties. Moreover, the validity of eggshell and wheat straw is recommended in further studies. The following treatments of wheat straw are recommended for further assessment and better results. Alkali modification is the ideal method for improving the strength of WS-FCC [106]. Alkaline treatment with sodium hydroxide alters the fiber morphology and crystallinity degree. This resulted in an increase in the mechanical properties in composites [107]. All LPPB mixtures experienced a drop in their compressive and splitting tensile strength values after the integration of wheat straw (treated and untreated). Still, the drop was less severe in the case of treated wheat straw mixtures attributable to the better bonding that sodium silicate forms [108]. Using these treatments might improve properties of fiber in case of partial cement replacements i.e., eggshells powder or other organic materials for better results.

3.2.8 Super Plasticizer

1.5% super plasticizer Sikament -512 PK by mass of cement from Sica company is used. It is a high range water reducing and set retarding concrete admixture. Sikament -512 complies with ASTM C-494 Type G and EN 934-2: 2001. Chemical composition of super plasticizer is mentioned in Table 3.1 provided by manufacturer. Figure 3.5 shows picture of Sikament -512 PK.

TABLE 3.1: Superplasticizer Specification by Manufacturer

Parameter	Values
Density at 250 C	1.16-1.2 Kg/lit
PH value	Approx 7
Product Color	Brownish Liquid
Type	Organic Polymer Blend

FIGURE 3.5: Sikament-512 PK

3.3 Mixing Procedure and Casting

For concrete to be workable and for better results at later days it needs to be mixed properly. First, materials are collected in different trays after weighing properly. Uniform mixing is done in drum mixer and checked properly. Tests for fresh properties including slump and compaction factor are done after mixing.

3.3.1 Mix Design

Mix design consists of ratios in which concrete elements are contributing to the mix. Bating ratio selected is 1:2:3 with 0.45 w/b and 1.5% super plasticizer by weight of binder. Wheat straw is added by wet volume of concrete i.e., 1%. This ratio is selected to have concrete with good strength and to have good quantity of cement to have good strength concrete. Partial replacements of cement are also done. Ceramic waste and eggshell powder are used to replace cement in different percentages. There has been considerable research on the use of ceramics as a replacement for cement. Ceramic has replaced cement up to 40% and provided improved properties [63, 64]. When CWP was used in concrete, lower percentages (10%-20%) have been reported to be more effective for cement substitute [109, 110]. The concept of using eggshells as a cement replacement is relatively novel. In this study, a fixed ceramic content of 15% and varying percentages of eggshells are used to partially replace cement at 5%, 10%, and 15%. Chong et el., [103] stated that eggshells can replace cement at different percentages i.e., 0-15%, 0-2%, and 0-25%, results in improved compressive strength. Partial replacement at 10% came out to be optimum in most of replacements. So, in this regard replacement of cement with a fixed percentage of ceramic powder i.e., 15% and varying percentage of eggshell powder i.e., 5, 10, and 15% is done to achieve sustainable construction for healthy environment. 5, 10, and 15% are selected keeping in mind the optimum percentage declared by Chong et al., [103] in most of the replacements i.e., 0-15%. Cement replacement up to 40% yielded good results, but in this study, the maximum replacement of cement is done up to 30%. Table 3.2 shows details of all mixes along with constituents.

3.3.2 Procedure

To create PC mix, cement, sand, and aggregates are added simultaneously into a drum mixer, followed by the addition of solution i.e., combination of water and superplasticizer. Superplasticizer is added to water to provide the required workability with a lower water-to-binder ratio. Superplasticizers offer significant

Table 3.2: Mix Design

Mix Name	Cement (%)	CWP (%)	ESP (%)	Fine Aggregate (%)	Coarse Aggregate (%)	W/B	WS by vol. of wet Concrete (%)	SP by weight of Binder (%)
PC	100	0	0	200	300	0.45	0	1.5
WSRC	100	0	0	200	300	0.45	1	1.5
PC-Ce15	85	15	0	200	300	0.45	0	1.5
WSRC-Ce15	85	15	0	200	300	0.45	1	1.5
WSRC-Ce15-ES5	80	15	5	200	300	0.45	1	1.5
WSRC-Ce15-ES10	75	15	10	200	300	0.45	1	1.5
WSRC-Ce15-ES15	70	15	15	200	300	0.45	1	1.5

improvements in the workability of concrete, without the risk of segregation, long-lasting control of slump loss, and no adverse effects on ultimate strength. The mixer is then set to rotate for a duration of five minutes. On the other hand, for WSRC preparation, the drum mixer is first loaded with 1/3 of cement, sand, aggregates, and straw, layered in four separate layers. The remaining materials are then added to the mixer using the same layering technique. Two-thirds of the required solution is then added, and the mixer is rotated for three minutes. The remaining one-third of solution is then added, and the mixer is started again for two minutes. However, at this stage, the mixture may still not be homogeneous and workable. To avoid the bleeding of WSRC due to addition of water and super plasticizer, the mixer is rotated for an additional three minutes to obtain a better, more homogeneous mix. Increasing the mixing time has proved to be a successful approach in obtaining a workable WSRC.

3.3.3 Casting Techniques

Cylinders and beams are prepared for casting including oiling and cleaning of molds. All molds are filled with concrete in three layers for uniform shape and mixing. Cylinder and beams used in this program are of size (102 mm x 204 mm) and (102 mm x 102 mm x 457 mm) respectively. All molds are thoroughly cleaned properly of all impurities and harden concrete already sticked. Then molds are oiled by used oil for proper placing of concrete. Tamping rods are used to compact concrete which was placed in three layers in all molds. After filling all molds these are then placed in open air. After enough setting of concrete molds are opened for curing which was done in curing tank. Figure 3.6 shows cylinders and beams used in this research program.

3.4 Testing Procedure

To understand concrete behavior under different conditions we have performed different type of tests. Fresh and harden properties can be determined by different tests which are mentioned below.

(a) (b)

FIGURE 3.6: Molds (a) Cylinders (b) Beams

3.4.1 Procedure for Fresh Properties Determination

Fresh properties are such properties which determine the workability and placement of concrete. Fresh properties were determined before casting concrete. Following fresh tests were performed.

3.4.1.1 Slump

The most easy method for determining the workability of new liquid phase concrete, as well as a relatively quick and affordable method, is the slump cone equipment test [111]. Since the 19th century, this reality has pushed workability tests to be widely used. The slump test is conducted using the procedures outlined in ASTM C143 (USA), IS: 1199 - 1959 (India), and EN 12350-2 (Europe). The most popular method for assessing the stream qualities of new concrete is the slump test, which provides a measure of workability [112].

By calculating the fall from the peak of the fresh concrete that has slumped using this technique, the slump may be estimated. Non-permeable base plate, measurement scale, and temping bar, along with slump cone shape. The test's shape is a frustum-cone with a top diameter of 10 cm, a foot diameter of 20 cm, and a height of 30 cm. The tamping bar is 60 cm long, 16 mm wide, and adjustable at one end.. Figure 3.7 shows appratus used for slump test.

3.4.1.2 Compaction Factor

Although the compacting factor test is primarily intended for use in laboratories, it can also be applied in the field [111]. It is frequently used when concrete is going to be compacted by shaking and is more precise and sensitive than the slump test. It is especially beneficial for concrete blends of extremely poor workability [111].

The method is applicable to plain and air-entrained concrete built with light, average weight, or massive aggregates having a nominal largest estimate of 38 mm or less, but it is not applicable to concrete that has no fines or is circulated with air. Using the hand scoop, carefully transfer the test piece of concrete into the higher container. The trap door may be opened when the container has been filled to the brim, allowing the concrete to descend into the bottom container. Immediately after the concrete has been placed to rest, the barrel should be made visible, the lower container's trap door should be unlocked, and the concrete should be allowed to fall into the barrel. Holding a trowel in each hand with the plane of the edges level, move one on each side over the finest of the barrel while simultaneously keeping them squeezed against the best edge of the barrel to cut off the excess concrete that is still present above the level of the beat of the barrel at that point. The ratio of the weight of concrete that has been largely compacted to concrete that has been fully compacted is known as the compacting factor.

Table 3.3: Workability Values

Workability	Compaction Factor
0.780	Very Low
0.850	Mild
0.920	Medium
0.950	High

It could be expressed frequently to the second decimal place closest. The two most often used techniques, Slump Cone and Compaction Factor (C.F.), were used in the consistency assessment step in accordance with IS: 1199:1959. Values for compaction factor ranges from 0.78 to 0.95 names as very low to high respectively shown in table 3.3. Figure 3.8 shows test setup for compaction factor.

3.4.2 Procedure for Density Determination

Harden properties were determined after curing of concrete. These properties include strength, density, and behavior under different conditions.

3.4.2.1 Fresh Density

Fresh density is performed to check weigh per unit volume of concrete at the time of casting. This test was performed to access the weight of mix design. Fresh densities help to compare all mixes to check for light weight, normal weight or heavy weight concrete. First of all weight of concrete is calculated in cylinder of known volume and weight, then weight of cylinder is subtracted from total weight. After calculating weight of concrete, it is then divided by volume of cylinder.

3.4.2.2 Harden Density

Harden density is performed to check weigh per unit volume of concrete at later stage after completing curing process. This test was performed to access the weight of mix design. Hard densities help to compare all mixes to check for light weight, normal weight, or heavy weight concrete. For harden concrete direct weight of cylinder is calculated using weighing balance and then divided by volume of cylinder. Figure 3.9 shows the process.

3.4.3 Procedure for Water Absorption and Mass Loss Determination

The measurement of water absorption is conducted in accordance with the ASTM C1585 standard, whereby the weight of oven-dried cylinders is recorded prior to immersion in water and subsequently, the weight of the wet cylinders is measured. This method allowed for accurate determination of the amount of water absorbed by the cylinders. The quantification of water absorption is achieved through the calculation of mass loss, which is determined as the difference between the weight of the wet samples and that of the oven-dried samples. This process helps to calculate water absorption and mass loss. For the water absorption test, exposure to high temperature in an oven after the curing process is required, which should be higher than 25 degrees celsius. To avoid any issues, separate cylinders are cast for the water absorption test.

3.4.4 Procedure for Mechanical Properties Determination

Mechanical properties define the behavior of sample under loading condition. These includes compressive and flexural strength as well as toughness.

3.4.4.1 Compressive Strength

The Universal Testing Machine (UTM) is used to measure the compressive strength, absorbed compressive energy (Ce), energy absorption up to the maximum stress (Cem), energy absorption after the maximum stress (Cep), and compressive toughness index (CTI) of cylinder specimens. The measurement range of the UTM is 0 to 1500 mm, with a resolution of 0.001 mm. The cylinders are tested in compression using ASTM C39/C39M-20 (Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens).

3.4.4.2 Flexural Strength

For the flexural strength test, according to ASTM C293/C293M-16, 18 beam-lets are prepared. The ASTM C293 standard prescribes the application of a center point loading, also known as one point loading, during testing. Determined are flexural behaviour, modulus of rupture (MOR), absorption of flexural energy, and flexural toughness index. The flexural test is a useful way to measure the tensile strength of concrete indirectly because the tensile stresses that develop on the bottom surface of the beam are a function of flexural stress. By measuring the maximum load that the beam can sustain before it fails, we can determine the flexural strength of the concrete and use this as an estimate of its tensile strength. Flexural tests produce a more stable load-deflection curve than splitting tests and can be used to obtain a more reliable estimate of the energy dissipation ability of rubberized concrete after cracking [113].

3.4.5 Procedure for Microstructural Analysis

Microscopic analysis determines internal behavior or making of concrete. It shows concretes structure from very close, to show how all components were bound together.

3.4.5.1 SEM analysis

SEM imaging is used to do a micro-structural investigation of HRC that has been tuned for bonding with concrete. This test aims to shed light on the micro-structure of selected concrete samples , how straw is mixed with concrete, the precise process of concrete bonding, and the type of failure/cracking. For scanning electron microscopic imaging, a VEGA3 TESCAN with a 10 kV voltage is used. Before testing, samples are plasma coated.

Chapter 4

Results and Discussion

4.1 Background

As mentioned in chapter 3 about materials and casting chapter 4 is about results and discussions. Different type of mixes were made in this research including PC, WSRC, PC-Ce15, WSRC-Ce15, WSRC-Ce15-ES5, WSRC-Ce15-ES10, and WSRC-Ce15-ES15. Fresh and harden properties of all mixes were calculated and observed after casting and after curing process. Different mixes showed different results depending on their compositions. Tests were performed according to standard and research done already in recent years.

4.2 Fresh Properties

4.2.1 Slump

Slump is measured for all mixes immediately after mixing procedure. PC shows a slump of 44.45mm which is greater than all other mixes. With the addition of fibers slump reduces and reaches zero with the inclusion of eggshell powder. Table 4.1 shows slump for all mixes altogether. Addition of natural fiber reduces slump of concrete which reduce workability of concrete. Slump of natural fiber reinforced concrete decreases. This might be due to the fact that a considerable amount of water is absorbed by the air-surface dried straw in WSRC mix. After treatment fibers are exposed to air which results in evaporation of moisture from fibers. Fibers then utilize required water from composite resulting in lower slump [108, 114–117]. In this research cement is also replaced by some waste materials, these replacements also shows impact on slump of concrete. As PC-Ce15 shows

Figure 4.1: Slump Test of WSRC

impressive decrease in slump as compared to PC. This practical shows that adding wheat straw to concrete or replacing cement at 15% with ceramic results in same slump. Addition of both wheat straw and ceramic to concrete reduces slump to 0. Eggshell along with ceramic and wheat straw proves to be less workable than all other mixes. Table 4.1 shows results for slump test. Figure 4.1 shows slump measuring process.

4.2.2 Compaction Factor

Compaction factor test is performed for all mixes after slump. Workability level according to values are given in Table 3.3. Compaction factor test also shows results similar to that of slump test. PC is found to be more workable than all other mixes, while the addition of fiber and cement replacement results in a reduction in the workability of concrete. WSRC proves to be less workable than PC-Ce15 but in slump they exhibit same value. WSRC-Ce15 followed by WSRC-Ce15-ES5, WSRC-Ce15-ES10, and WSRC-Ce15-ES15 shows descending trend of workability respectively. Table 4.1 shows results for compaction factor test. Figure 4.2 shows the weighing process adopted in this test.

Figure 4.2: Compaction Factor Weighing

4.3 Density

4.3.1 Fresh Density

Fresh density of all mixes is calculated with compaction factor test. All mixes possess different densities depending upon constitution. Table 4.3 shows fresh densities of all mixes. Weight of compacted cylinder in case of compaction factor is calculated then the weight of empty cylinder is subtracted from total weight. Weight of concrete is then divided by volume of dedicated cylinder. PC, Pc-Ce15, and WSRC-Ce15-ES10 shows approximately same density which indicates that they posses same weight if poured in volume of 1m3 which is higher than all other. WSRC-Ce15 is found to be light weight concrete if compared to all other

Table 4.1: Slump and Compaction Factor

Sample ID	Slump (mm)	Free Fall Weight (Kg)	Compacted Fall Weight (Kg)	Compaction Factor
PC	44.75	9.965	12.185	0.8178
WSRC	25.4	9.01	11.46	0.7862
PC-Ce15	25.4	9.856	12.205	0.8075
WSRC-Ce15	0	8.156	10.485	0.7778
WSRC-Ce15-ES5	0	8.256	10.645	0.7755
WSRC-Ce15-ES10	0	9.375	12.195	0.7687
WSRC-Ce15-ES15	0	8.715	11.575	0.7529

mixes follows by WSRC-Ce15-ES5, WSRC, and WSRC-Ce15-ES15 respectively. Density of natural fiber reinforced concrete decreases. It might be due to the presence of low-density straw in WSRC specimens. Natural fibers possess lower density as compared to steel and synthetic fibers. Less dense fibers when added to concrete, results in reduction of density of composites as compared to PC/Parent mix [115, 118–123]. This research shows that if we add wheat straw to PC-Ce15, resulted mix WSRC-Ce15 came out to be less denser than PC, PC-Ce15, and WSRC. Increment of eggshell percentage shows irregular trend as WSRC-Ce15-ES10 exhibit maximum weight as compared to WSRC-Ce15-ES5 and WSRC-Ce15-ES15. Table 4.2 shows results for fresh density. Figure 4.2 shows the weighing process.

4.3.2 Hardened Density

Hardened density of all mixes is calculated with compaction factor test. All mixes possess different densities depending upon constitution. Table 4.2 shows Hardened densities of all mixes. Hardened density shows slightly different trend as compared

Table 4.2: Fresh and Harden Density

Sample ID	Fresh Density (Kg/m^3)	Harden Density (Kg/m^3)
PC	2191.55	2428.13
WSRC	2061.15	2365.63
PC-Ce15	2195.14	2403.13
WSRC-Ce15	1885.79	2265.63
WSRC-Ce15-ES5	1914.57	2287.50
WSRC-Ce15-ES10	2193.35	2231.25
WSRC-Ce15-ES15	2081.84	2265.63

to fresh densities. PC is found to be denser than all other mixes followed by PC-Ce15, WSRC, WSRC-Ce15-ES15, WSRC-Ce15-ES5, WSRC-Ce15, and WSRC-Ce15-ES10 respectively. WSRC-Ce15-ES10 which is one of more dense mix in fresh densities is found least dense than all other mixes. Presence of eggshell in concrete along with ceramic as cement replacement in wheat straw reinforced concrete proves to unpredictable in all tests. Table 4.2 shows results for fresh density.

4.4 Water Absorption and Mass Loss

Physical properties including water absorption and mass are mentioned in table. Every mix with different composition behaves with water differently. Table 4.3 shows results of mass loss and water absorption. Water absorption shows the quantity of water absorbed by concrete sample during the process of soaking in water. CPC shows more absorption than PC and WSRC-Ce15 shows more absorption than WSRC. This trend shows that presence of ceramic in concrete increase water absorption of samples. WSRC and WSRC-Ce15 shows more absorption than PC and PC-Ce15 respectively, this proves that wheat straw was also responsible of more water absorption in concrete. Water absorption of natural fiber reinforced concrete shows increment. The reason could be that high requirement of water absorption of natural fibers [108, 124]. Eggshell along with ceramic in wheat straw

Table 4.3: Water Absorption and Mass Loss

Sample ID	Mass Loss (Wet-Dried) (Kg)	Water Absorption (%)
PC	0.053	1.346
WSRC	0.078	2.019
CPC	0.056	1.436
WSRC-Ce15	0.095	2.554
WSRC-Ce15-ES5	0.07	1.877
WSRC-Ce15-ES10	0.13	3.513
WSRC-Ce15-ES15	0.115	3.075

reinforced concrete showed irregular trend of water absorption as WSRC-Ce15-ES10 shows more water absorption than all other mixes while WSRC-Ce15-ES5 shows water absorption even less than WSRC and WSRC-Ce15. WSRC-Ce15-ES15 shows water absorption less than WSRC-Ce15-ES10 but more than all other mixes. Combination of both waste materials in wheat straw reinforced concrete is never done before. Water absorption of eggshell as partial cement replacement shows increment. The reason could be that high surface area as compared to that of cement [62, 105]. There might be an issue of improper curing or human error during casting. In the case of eggshells at 5% water absorption is decreased which shows irregular trend. This might be due to less curing of samples or disturbance of pores lining due to human error in casting. Mass loss showed similar trends as water absorption. Table 4.3 shows result for all tests mentioned.

4.5 Mechanical Properties

4.5.1 Properties Under Compressive Loading

All mixes react differently under loading conditions applied uniformly. PC-Ce15 shows more strength than all others which is 22.34 MPa. Presence of 15% ceramic in PC-Ce15 instead of cement proves to be more suitable for concrete in term of strength. Ceramic waste powder as partial cement replacement results in higher strength. This might be due to presence of CaO in ceramic powder. Additional amount of CaO along with cement provided higher strength. Ceramic tiles when crushed properly, provide binding properties to concrete as cement and reduce pores in concrete, higher strength is achieved [63, 64, 109]. PC mix stand second in terms of strength with 20.48 MPa. Behavior of mixes under compressive loading is shown in Figure 4.3. WSRC shows higher strain value with lowest strength as compared to PC, PC-Ce15, and WSRC-Ce15-ES15. PC and PC-Ce15 mixes

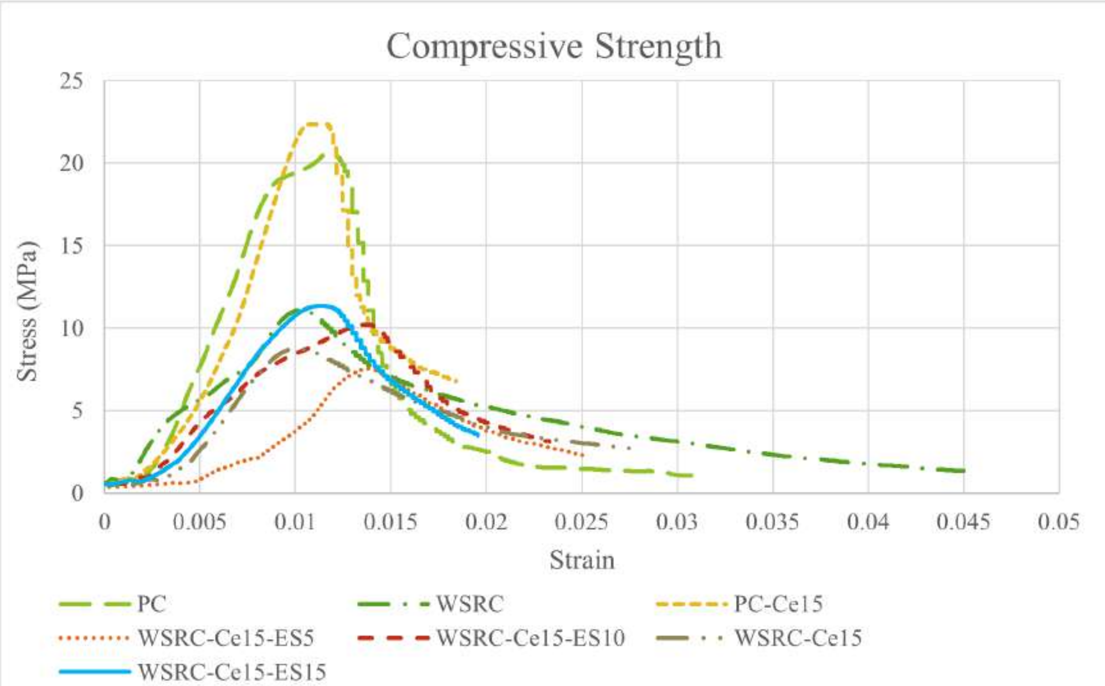

FIGURE 4.3: Compressive Behavior

shows higher strengths than all other but quick failure is observed as compared to all other mixes. Presence of fibers in wheat straw incorporated mixes shows higher strain values if compared to PC and PC-Ce15. Addition of natural fibers in concrete results in reduction of compressive strength which is already proved from literature. The compressive strength of natural fiber reinforced concrete shows decrease as compared to that of PC. The reason might be the presence of less dense fibers. Fibers result in creating pores due to improper distribution. As fibers reduce the amount of basic concrete ingredients and cover their place, results in reduction of strength as compared to PC mix [115, 124–130]. Similar results are observed in this research, but combination of eggshell and ceramic was never tested before any fiber reinforced concrete or normal concrete. If we compare all mixes with fibers then WSRC-Ce15-ES15 showed more strength than all others including WSRC, WSRC-Ce15, WSRC-Ce15-ES5, and WSRC-Ce15-ES10. This shows that presence of eggshell and ceramic in equal proportion is found more suitable in terms of strength which is 11.36 MPa. The fineness of eggshell powder also had significant influence on the compressive strength of concrete [62]. Eggshell incorporated mixes show higher strength if properly pulverized as required. Incorporation of eggshell and ceramic waste powder in concrete as partial cement replacement shows improvement in strength as compared to parent fiber reinforced mixes, presence of CaO in both replacements is found useful in concrete.

Figure 4.4 shows the cracks at ultimate load and tested specimens. PC mix shows abrupt failure at peak point as compared to all other mixes. PC-Ce15 shows more resistance to cracks is compared to PC. On the other hand presence of fibers re-

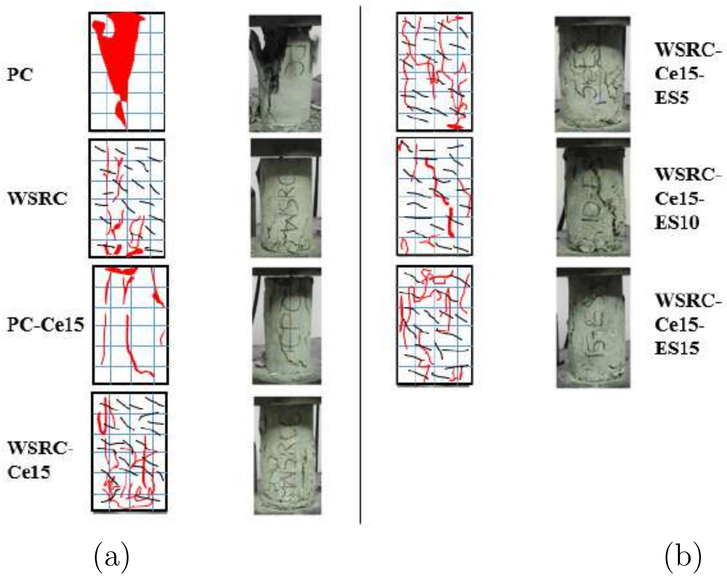

FIGURE 4.4: Compressive Tested Specimen, (a) Cracks at Ultimate Load and Tested Specimen without ESP (b) Cracks at Ultimate Load and Tested Specimen with ESP

sisted cracks at higher extent. Spalling of concrete is observed in case of PC. PC-Ce15 shows spalling when it is removed from assembly. Fiber incorporated mixes shows bridging effect at ultimate load. When the first crack is generated, tensile capacity of fibers resist crack formation. This resistance enhances the energy absorption of composite resulting in a higher toughness index [115, 124, 131].It is observed from Figure 4.4 that small cracks are generated on the surface of fiber incorporated cylinders at ultimate load. Concrete elements remain intact even after removal from assembly.

TABLE 4.4: Compressive Strength Properties

Sample ID	Stress (MPa)	Cem (MJ/m^3)	Cep (MJ/m^3)	Ce (MJ/m^3)	CTI -
PC	20.48	0.129	0.076	0.205	1.592
WSRC	11.10	0.059	0.145	0.204	3.462
PC-Ce15	22.34	0.108	0.073	0.181	1.669
WSRC-Ce15	8.75	0.039	0.087	0.125	3.250
WSRC-Ce15-ES5	7.54	0.036	0.050	0.086	2.384
WSRC-Ce15-ES10	10.19	0.077	0.055	0.132	1.708
WSRC-Ce15-ES15	11.36	0.057	0.058	0.116	2.003

Values of stress, Cem, Cep, Ce, and CTI are mentioned in Table 4.4. Compressive energy absorption (Ce) for all blends is computed using the area under stress-strain curves, and this has also been done by [129, 132, 133]. The energy absorption per cubic metre of concrete is measured in MJ/m^3 [127, 134]. The remaining two parts of this total energy are the energy absorbed up to the maximum stress (Cem) and the energy absorbed from the maximum stress to the maximum strain (Cep). However, the toughness index is derived using the Ce/Cem ratio (CTI). Compressive toughness index is higher in case of WSRC. PC mix shows lower toughness index as compared to all other mixes. WSRC-Ce15-ES5 shows higher toughness index as compared to all other eggshell incorporated mixes but, lower strength than all other mixes

Figure 4.5 shows the percentage comparison between compressive aspects of all mixes. Line is drawn at 100% showing PC and all other mixes are compared accordingly. There is reduction of 46.35% strength in WSRC as compared to PC while 61% in WSRC-Ce15 as compared to PC-Ce15. WSRC-Ce15-ES15 shows more strength as compared to both WSRC and WSRC-Ce15, which shows that while using natural fiber i.e., wheat straw, we can reduce quantity of cement by even 30% to get similar or more strength. Incorporation of eggshell as partial cement replacement shows increment in compressive strength[60, 61, 135].

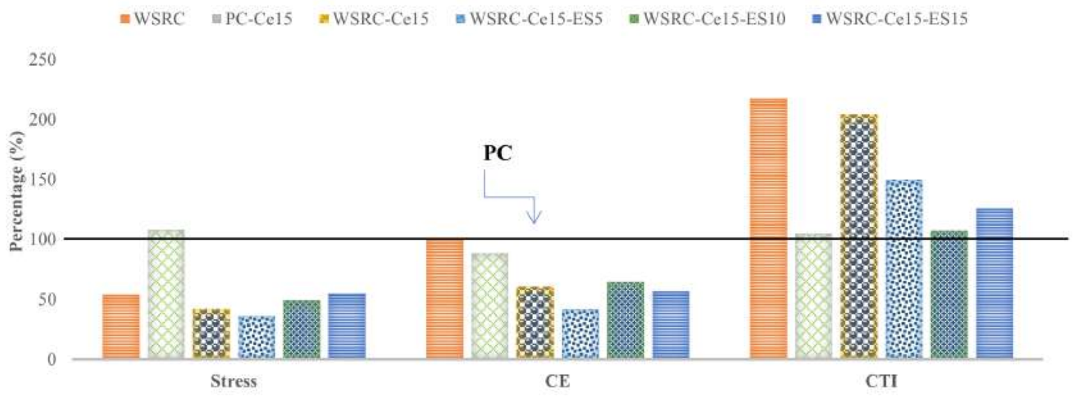

Figure 4.5: Comparison of Compressive Results

PC-Ce15 shows less toughness as compared to PC while WSRC-Ce15 shows less toughness as compared to WSRC. Eggshell incorporated mixes shows less toughness index than WSRC and WSRC-Ce15 but higher toughness is observed as compared to PC and PC-Ce15.

4.5.2 Properties Under Flexural Loading

All mixes react differently under loading conditions applied uniformly. PC shows more flexural strength than PC-Ce15 and all other mixes which is 9.228 MPa. WSRC shows more flexural strength than all other fiber incorporated mixes which is 6.254 MPa. WSRC-Ce15-ES15 showed strength approximately same as WSRC but 49% lesser than PC. Flexural strength increases with increase in eggshell powder quantity. WSRC-Ce15 shows flexural strength lesser than both WSRC and WSRC-Ce15-ES15 by 6% and 4% respectively. Presence eggshell shows enhancement in flexural strength when compared to WSRC-Ce15 at 15%. Behavior of mixes under flexural loading is shown in Figure 4.6. It is observed that the PC and PC-Ce15 mixes exhibit abrupt failure in comparison to those that are reinforced with fibers. The fiber-reinforced mixes exhibit energy absorption after first crack propagation, resulting in ductile behavior as compared to PC and PC-Ce15. So, it is concluded that cracks can be delayed by the addition of fibers while tensile strength of fibers ultimately contributes towards the overall gain in flexural strength as well. Similar behavior was also reported by Yoo and Moon [136].

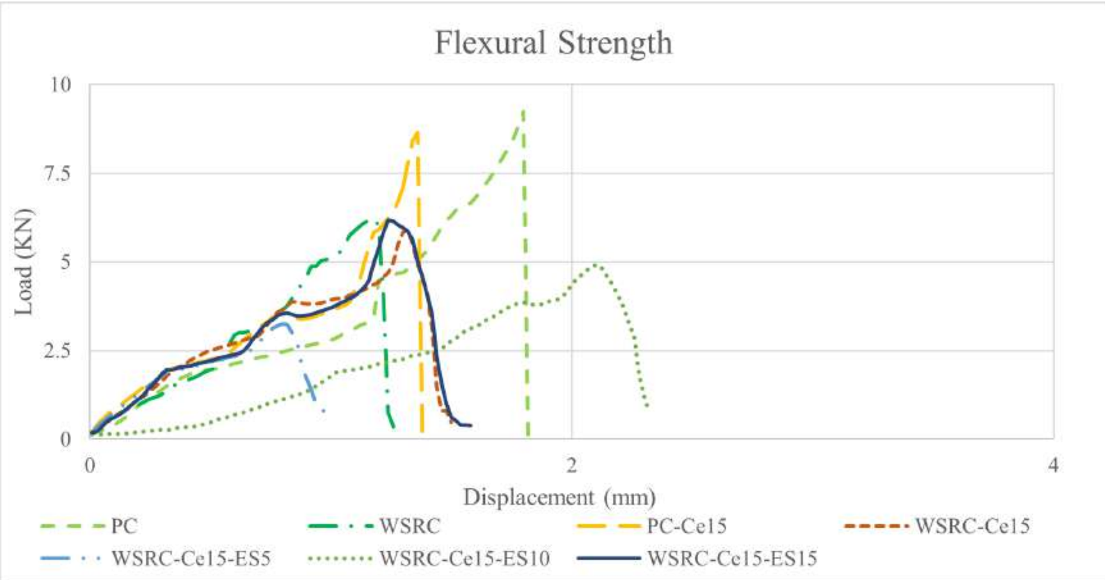

FIGURE 4.6: Flexural Behavior

Crack at ultimate load and tested specimens are shown in Figure 4.7. Even after cracking, the WSRC, WSRC-Ce15, WSRC-Ce15-ES5, WSRC-Ce15-ES10,

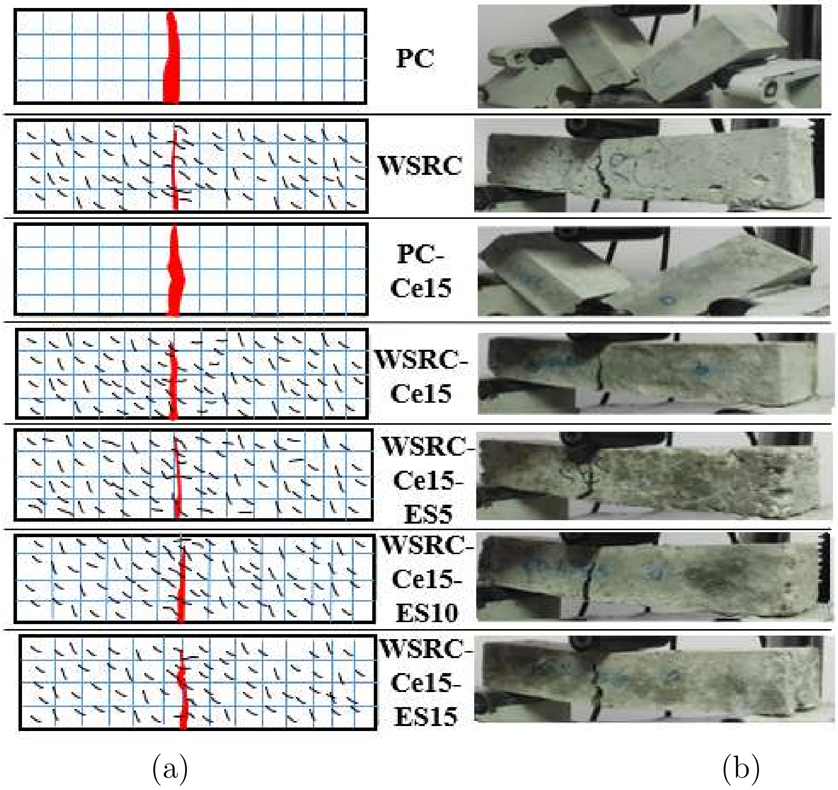

FIGURE 4.7: Flexural Tested Specimen, (a) Cracks at ultimate load (b) Tested specimen

and WSRC-Ce15-ES15 specimens are able to withstand the application of load. Natural fibers create bridging mechanism which resist the cracking and caused enhanced energy absorption for post-crack behavior [124, 137]. As load is applied at center of beam so the maximum moment generated at bottom and crack initiated from there.In the case of PC and PC-Ce15 mixes, the sudden failure is observed at the peak point of the load-displacement curve, indicating the brittle nature of concrete. This sudden failure is attributed to the propagation of a single dominant crack that reaches the ultimate tensile stress of concrete, resulting in complete failure. This type of failure is not desirable in structural elements, as it provides no warning before complete collapse, which can be dangerous. During flexural testing, a single crack at the bottom is generated as a result of center-point loading. In the case of WSRC, the presence of fibers delayed the formation of the first crack, fibers provided bridging mechanism which delayed the formation of cracks and enhanced load taking capability by delaying failure time due to tensile strength of fibers. Similar trend was also reported by Kene et al., [138].

Values of load, MOR, Fem, Fep, Fe,and FTI are mentioned in Table 4.5. The

Table 4.5: Flexural Strength Properies

Sample ID	Load (KN)	MOR (MPa)	Fem (J)	Fep (J)	Fe (J)	FTI -
PC	9.228	5.363	6.148	0.0	6.148	1
WSRC	6.254	3.635	3.374	0.283	3.658	1.084
PC-Ce15	8.646	5.026	4.297	0.0	4.297	1
WSRC-Ce15	5.898	3.428	3.766	0.570	4.336	1.159
WSRC-Ce15-ES5	3.252	1.890	1.478	0.391	1.869	1.265
WSRC-Ce15-ES10	4.916	2.857	4.002	0.757	4.759	1.189
WSRC-Ce15-ES15	6.170	3.586	3.280	1.139	4.419	1.347

Modulus of Rupture is calculated using the maximum load from the load displacement history observed under flexural loading (MoR) [139, 140]. According to ASTM C293/C293 M-16, the MoR is calculated using the maximum load from the load displacement history observed under flexural loading (MOR). According to ASTM C293/C293 M-16, the MOR of all mixtures is determined using the equation MOR = 3Pl/2bd2 (Standard Test Method for Flexural Strength of Concrete - Using Simple Beam with Centre-Point Loading). Where P is the maximum load and L, b, and d are the tested mix beam specimens' dimensions, i.e., length, breadth, and depth. L= span length=406mm. When values are with PC, the Modulus of Rupture (MoR) of all specimens is somewhat reduced. Among all straw reinforced concrete specimens, the maximum MoR is of WSRC (i.e., 3.635 MPa), which is 33% less than that of PC. The region underneath the flexural load displacement history up to the point of greatest load is determined by the energy absorbed by the specimen under flexural loading up to the point of maximum load (Fem). The area beneath the history of flexural load displacement after the highest load up until the test's conclusion is known as the "energy absorbed by the specimen after the maximum flexural load" (Fep). The summation of Fem and Fep or the whole area underneath flexural load displacement history is taken as the flexural energy absorbed (Fe). The ratio of the energy absorption under flexural loading to the energy absorption up to the maximum flexural load (i.e., Fe / Fem) is taken as the flexural toughness index (FTI) . Each mix when compared to PC showed increase in toughness index. Maximum toughness index was observed in the case of ES15 with highest load than other eggshell incorporated mixes.

Figure 4.8 shows the comparison between different aspects of flexural testing. Concluded values in Figure 4.8 are ultimate load, modulus of rupture, total energy absorbed, and flexural toughness index. Line at 100% is drawn for PC and all other mixes are compared accordingly. Percentage increase and decrease in the values of all mixes as compared to PC is shown. In case of ultimate load, MOR, and Fe, PC stands higher than all other mixes but, FTI of PC is lower than all other mixes, WSRC-Ce15-ES15 stands at top. WSRC-Ce15-ES15 shows approximately equal drop as WSRC in load as compared to PC. Energy absorbed by PC from start to peak point is higher than all other mixes but toughness index is lowered comparatively.

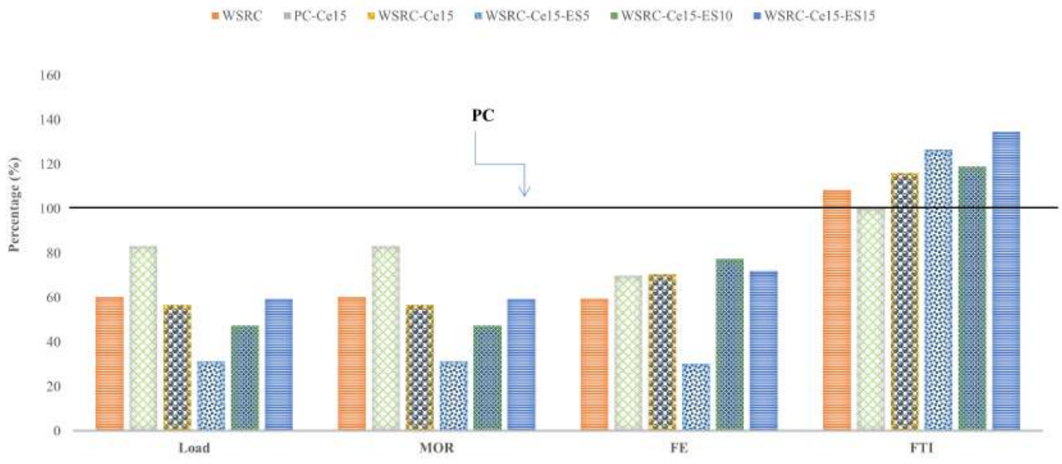

FIGURE 4.8: Comparison of Flexural Results

4.6 Microstructural Analysis

4.6.1 SEM

In Figure 4.9 (a), the rough texture of fiber shows that it has a bond with concrete. Applied load overcome bond between fiber and concrete, as one end of fiber is broken. This might be the reason behind lower compressive strength. Figure 4.9 (b) shows air voids with fibers in them. This clearly explain the reason behind bridging effect. Higher water absorption is also because of voids. Cluster of concrete with fiber at one end. Improper distribution of fibers, reason behind lower compressive strength as compared to PC and other WSRC mixes, can be seen in Figure 4.9 (c). Figure 4.9 (d) shows improper breakdown of fiber. This shows that fiber has resisted applied load up to some extent. Potential reason behind bridging effect. Energy absorption after peak point shows sequence. Cluster of concrete is seen in one of the views of Figure 4.9 (e) which shows brittleness of ceramic incorporated mix with lower energy absorption as compared to WSRC. Voids along with fiber addition. Reason behind higher water absorption and lower density as compared to PC, observed in Figure 4.9 (f).

In Figure 4.10 finer internal structure is observed, higher water absorption resulted. Fine structure was observed, as eggshell powder came out to be finer material from cement and ceramic waste powder. In Figure 4.10 (a) pullout of fiber is

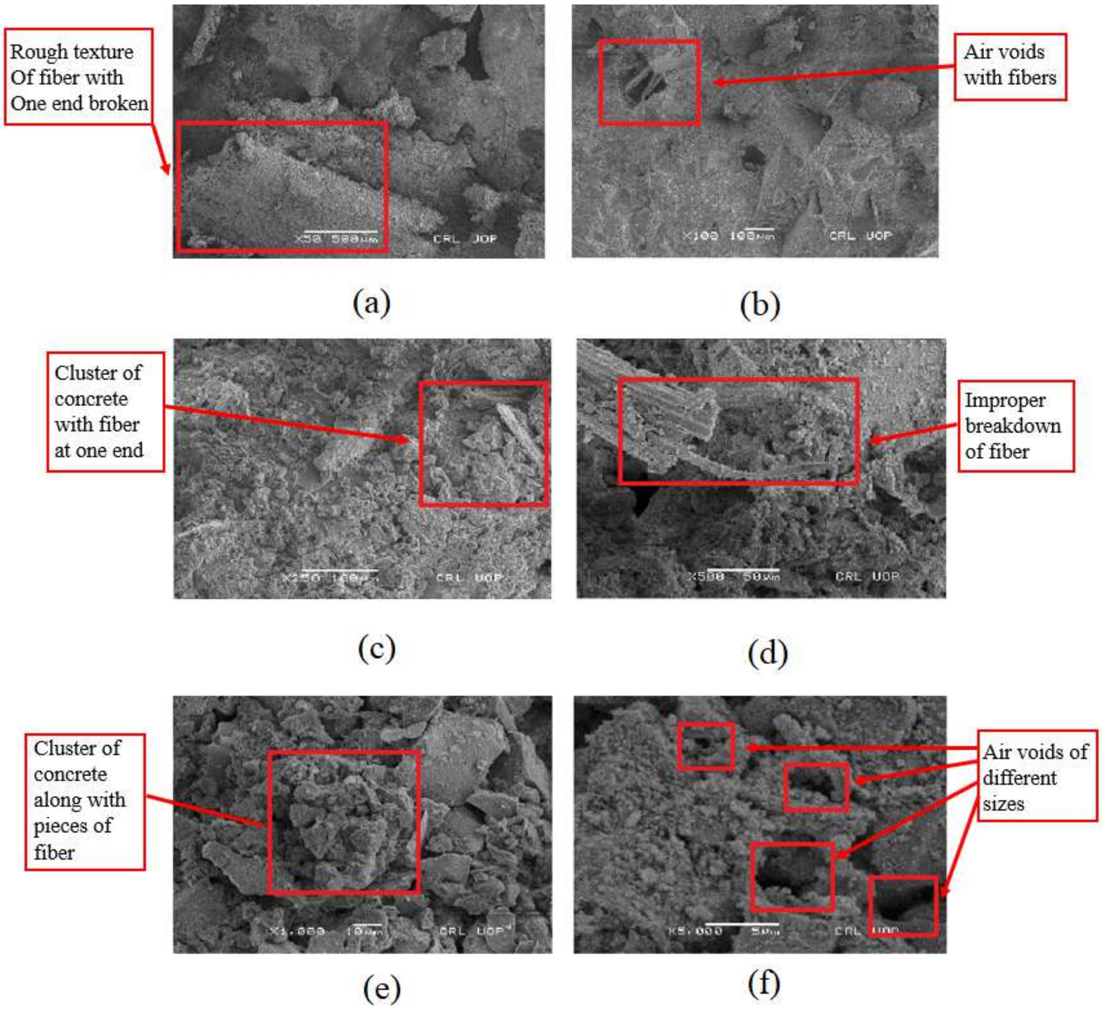

FIGURE 4.9: SEM of WSRC-Ce15, (a) Rough Texture (b) Air Voids with Fibers (c) Cluster of Concrete (d) Improper Breakdown (e) Cluster with Fiber (f) Air Voids

observed. Fiber internal capacity is greater than load applied, reason behind energy after peak. Figure 4.10 (b) shows fiber with only small piece removed, bonded with concrete from both ends, justifying bridging effect and delayed failure time. In Figure 4.10 (c) hairline and finer internal structure are observed as compared to WSRC-Ce15; higher water absorption resulted. Concrete was clearly observed as porous from internal view, aggregate size and non-uniform mixing, reason behind lower compressive strength, higher water absorption also resulted, shown in Figure 4.10 (d). In Figure 4.10 (e) fibers are not visible, improper distribution. This can be the reason behind an irregular drop in strength as fibers are not uniformly displaced. In Figure 4.10 (f), it shows clusters of concrete with small voids, lower density with increased water absorption. SEM analysis shows voids in both the specimens. WSRC-Ce15 and WSRC-Ce15-ES15 showed maximum water absorption than PC and PC-Ce15 and no slump, voids can be

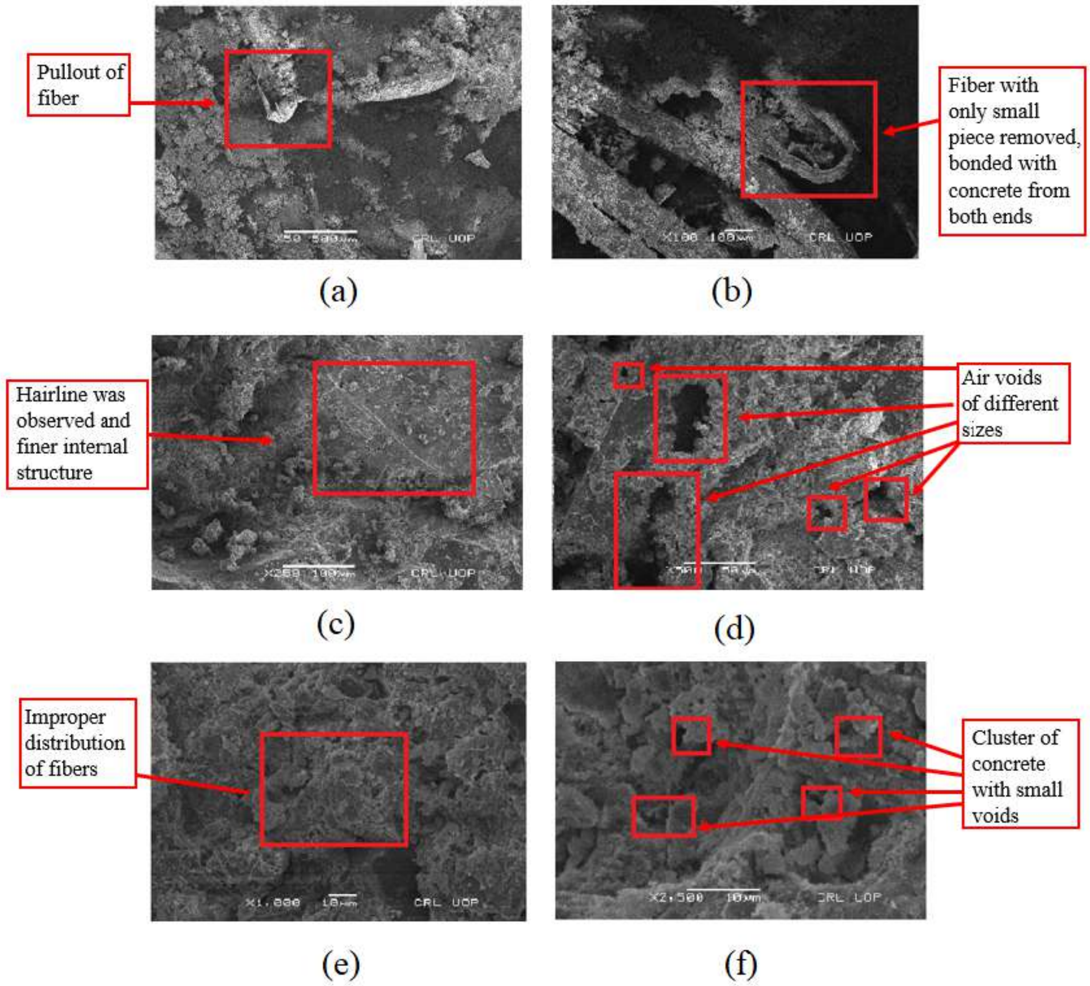

FIGURE 4.10: SEM of WSRC-Ce15-ES15, (a) Pull Out (b) Fiber with small piece removed (c) Fine Internal Structure (d) Air Voids (e) Improper Distribution (f) Cluster of Concrete

potential reason in case of both samples. Improper distribution of fiber is observed in both samples, showing human error during casting, reason behind irregular trends in results.

4.7 Summary

Combine effect of eggshell and waste ceramic powder has been explored in this chapter. Varying percentages of waste materials has replaced cement with same percentage of wheat straw and super plasticizer. Fiber addition was done by volume of wet concrete by 1%. Varying percentages selected for ceramic is 15% in all mix with 5,10, and 15% percent of eggshell in fiber reinforced concrete.

Compressive and flexural strength as well as toughness was concluded in this chapter along with all other properties including fresh, hard, and microstructural analysis. PC-Ce15 showed maximum compressive strength and WSRC showed maximum toughness index. PC showed maximum flexural strength and WSRC-Ce15-ES15 showed maximum toughness. WSRC-Ce15-ES15 showed maximum water absorption with maximum shrinkage. PC came out to be most workable as compared to all other mixes. WSRC-Ce15, WSRC-Ce15-ES5, WSRC-Ce15-ES10, and WSRC-Ce15-ES15 showed zero slump, WSRC and PC-Ce15 showed slump of 25mm while PC showed slump of 43.75mm.

In case of plain concrete PC-Ce15 is optimised as it posses greater compressive strength than all other mixes and structures where maximum compressive strength is required as concrete is renowned for its compressive dominant behaviour. WSRC-Ce15-ES15 is optimised in case of fiber reinforced concrete due to its higher compressive strength than all other fiber reinforced concrete. Secondly, WSRC-Ce15-ES15 posses maximum flexural toughness index than WSRC and WSRC-Ce15 with flexural strength approximately equal to that of WSRC and greater than WSRC-Ce15. Replacement of cement in WSRC-Ce15-ES15 is 30% which is higher than all other mixes and it posses acceptable properties. Acceptable results with lower cement content concluded WSRC-Ce15-ES15 as optimised mix and recommended for further studies and non-structural member at first.

Chapter 5

Discussion and Practical Implementation

5.1 Background

Results are obtained from after performing physical and mechanical testing on specimens of all mixes. Quantity of CWP remained same in all ceramic incorporated mixes i.e., 15% and varying quantity of ESP i.e., 5%, 10%, and 15%. Wheat straw quantity remained same in all FRC mixes i.e., 1% by volume of wet concrete. Results from physical and mechanical testing shows the combined effect of ES and CWP as partial cement replacement in WSRC. Data from above mentioned testings is utilized to evaluate optimized mix. Comprehensive discussion on practical implementation of this study and optimized mix is done in this chapter.

5.2 Optimum Combination of ES and CWP in WSRC

Results obtained from physical testing are analysed in Table 5.1. Results from compressive and flexural testing are mainly observed in selection of optimised mix

Table 5.1: Comparison of all Mixes

Sample ID	C.S MPa	Ce MJ/(m^3)	CTI -	Load KN	MOR MPa	Fe J	FTI -
PC	20.48	0.205	1.592	9.228	5.363	6.148	1
WSRC	11.10	0.204	3.462	6.254	3.635	3.658	1.084
PC-Ce15	22.34	0.181	1.669	8.646	5.026	4.297	1
WSRC-Ce15	8.75	0.125	3.250	5.898	3.428	4.336	1.159
WSRC-Ce15-ES5	7.54	0.086	2.384	3.252	1.890	1.869	1.265
WSRC-Ce15-ES10	10.19	0.132	1.708	4.916	2.857	4.759	1.189
WSRC-Ce15-ES15	11.36	0.116	2.003	6.170	3.586	4.419	1.347

Table 5.2: Optimized Mixes

Sample ID	C.S MPa	Ce MJ/m^3	CTI -	Load KN	MOR MPa	Fe J	FTI -
PC	20.48	0.205	1.592	9.228	5.363	6.148	1
PC-Ce15	22.34	0.181	1.669	8.646	5.026	4.297	1
WSRC-Ce15 -ES15	11.36	0.116	2.003	6.170	3.586	4.419	1.347

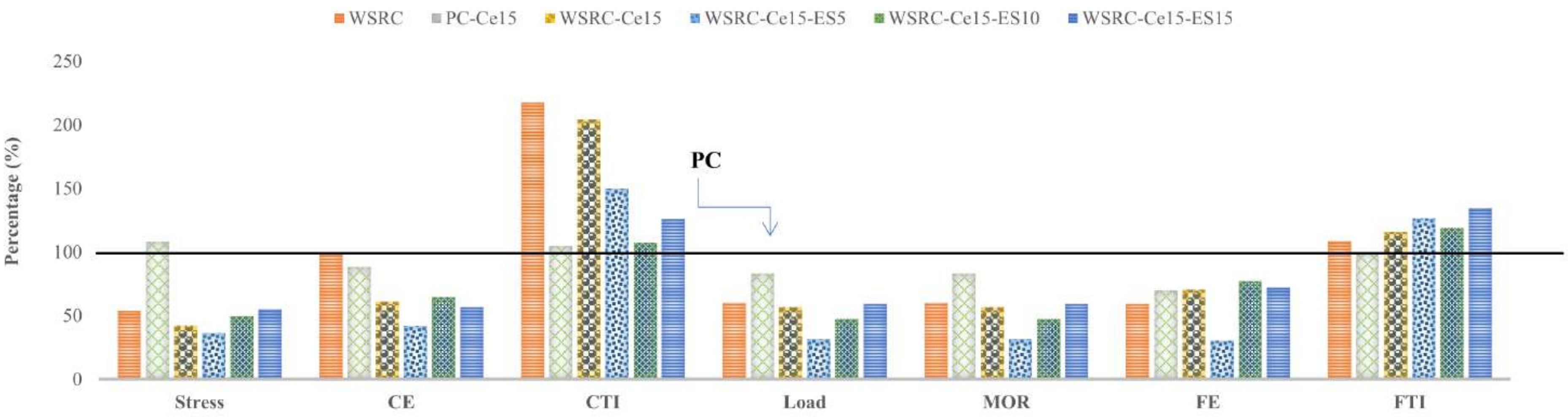

Figure 5.1: Comparison of all Mix

along with other properties. Firstly, replacement in PC mix is observed then in WSRC. ESP has only replaced cement in WSRC for production of eco-friendly concrete. PC-Ce15 has showed maximum compressive strength than all other mix with 9% increment than PC. The increase in strength of PC-Ce15 along with 15% cement reduction has highlighted it as optimized mix for high compressive demanding applications. WSRC-Ce15-ES15 is selected as optimized mix among other mixes. Reason behind selection of this mix is to produce eco-friendly concrete along with improved properties. WSRC-Ce15-ES15 showed 2% more compressive strength than WSRC while 29% more than WSRC-Ce15. The compressive toughness index of WSRC-Ce15-ES15 is significantly lower than that of WSRC and WSRC-Ce15 due to an increase in compressive strength. However, it is still higher than that of PC and PC-Ce15.

In case of flexural strength PC-Ce15 has showed lower strength than PC by 6% only. This behavior of PC-Ce15 has provided it benefit over PC as there is 15% less cement consumption. WSRC-Ce15-ES15 showed only 1% less than that of WSRC while 3% increment is observed than WSRC-Ce15. WSRC-Ce15-ES15 showed more FTI than PC, WSRC, PC-Ce15, and WSRC-Ce15 by 35%, 24%, 34%, and 16%. As 30% cement is replaced in WSRC-Ce15-ES15 by ESP and CWP equally. Reduction of this much cement in a mix along with improved properties has influenced the selection WSRC-Ce15-ES15 as optimized mix. Other properties including slump, C.F, and water absorption has no direct impact on selection of optimized mix as these can be influenced by simple additives. Slump and workability decreased in case of FRC while water absorption increased with addition of fiber as well as ESP. Densities of FRC decreased, either fresh or hard density. Table 5.1 and Figure 5.1 shows the comparison of all mixes. Table 5.2 shows optimized mixes along with PC mix.

5.3 Real Life Application

The foundation of civil engineering constructions used under a variety of loading conditions, including mechanical and dynamic loading, is concrete. Concrete production is the process which utilize many constituents. Constituents of concrete includes cement, sand, aggregate, water, and additives. As with increasing population demand for shelter increases, which is directly increasing the quantity of concrete required.

With the increase in concrete production, use of natural resources increases. Demand for cement is increasing day by day which is disturbing nature directly. This research has focused on replacing cement content in concrete for eco-friendly construction. Similarly, cracks in concrete appear at early ages as well as later stages. These cracks increase water absorption of concrete with time due to minor cracks. ES and CWP were used as partial cement replacement in concrete to reduce the utilization of natural resources. Fiber is used to tackle surface cracks and enhance energy absorption. PC-Ce15 has shown maximum compressive strength with 15% cement reduction. This mix can be used in members with high compressive strength demand i.e., coloumns. Coloumns act as critical members in frame structure incorporating compression. PC-Ce15 showed compressive strength more than PC which can be utilized in columns for higher compression along with lower cement content. There are many members in construction industry which requires high strength concrete, PC-Ce15 showed more strength as compared to PC mix which is bright sign for higher strength with lower amount of cement in concrete. In case of FRC, WSRC-Ce15-ES15 showed more compressive strength than all others mixes. In daily life construction, on sites parapets, coping, plain binding concrete, and fascia walls are not of high strength concrete. These can be executed by using normal strength or low strength concrete. WSRC-Ce15-ES15 will help in tackling surface cracks and members where higher strength is not required i.e., parapets, coping, plain binding concrete, and fascia walls. In this way we can reduce quantity of cement by 30% in members where compressive strength is not as issue. Concrete in these elements is usually lesser in quantity as compared to complete structure so, we can easily start replacing smaller things which then leads to bigger achievements at later stages. PC-Ce15 and WSRC-Ce15-ES15 can be used in building construction altogether. Critical members will be made using PC-Ce15 for higher strength and WSRC-Ce15-ES15 will be used in making of small, architectural, and supporting members. Even in bridge construction we can use both these mixes together, in main members i.e., piles, piers, and girders we can use PC-Ce15 while in deck slab, parapets, and architectural members we can use WSRC-Ce15-ES15. Fiber reinforced concrete can help in resistance to crack formation at surface along with lesser cement. This is how properties of concrete are improved and on the other hand sustainability is achieved.

Chapter 6

Conclusion and Future Recommendation

6.1 Conclusion

Wheat straw reinforced concrete was selected to implement virgin idea of replacing cement with two different type of waste materials altogether. Varying percentages of eggshell powder with fixed percentage of ceramic waste powder is selected for partial cement replacement. The idea was selected for betterment of environment and fresh atmosphere. Proper mixes were made with proper supervision and results were produced. Different types of test were performed on concrete composites with different composition. Results were produced from tests performed, output of which is concluded below.

- Mixes with fiber addition results in less workable concrete. PC mix showed maximum slump and conmpaction factor i.e., 43.75mm and 0.8178 respectively. Density of fiber reinforced concrete shows visible decrement than that of PC and PC-Ce15 i.e., fresh and harden density. Mixes with fiber addition shows maximum water absorption as compared to that of PC and PC-Ce15. Presence of fibers increase water absorbing capacity of concrete.
- PC-Ce15 showed maximum compressive strength than PC. Presence of ceramic in concrete at 15% came out to be more beneficial in terms of strength

as it shows approx. 9% increment than PC. WSRC-Ce15-ES15 shows more compressive strength than parent mix WSRC and WSRC-Ce15 by 2% and 29% respectively. This shows that addition of eggshell in addition to ceramic can produce improved results than only ceramic in concrete. Compressive strength of WSRC is also less than that of WSRC-Ce15-ES15.

- WSRC showed maximum energy absorption as compared to all other mixes, which is already proven from previous research. However, with the addition of eggshell powder in concrete, the compressive toughness index of the mixture decreased, but it remained higher than that of PC and PC-Ce15. Lowest compressive toughness index is observed in the case of PC.

- Maximum load in the case of flexural strength is observed in the case of PC i.e., 9.228 KN. WSRC-Ce15-ES15 showed approximately equal load as compared to WSRC as decrement of 2% is observed. WSRC-Ce15 showed lesser load than WSRC-Ce15-ES15 by 4%.

- Flexural toughness index is higher in the case of WSRC-Ce15-ES15 followed by WSRC-Ce15-ES5 by 35% and 27% as compared to PC respectively. Presence of eggshell showed the increase in toughness index which is clearly a good sign for further inspection.

- SEM analysis showed similar trends in both cases of separately ceramic and combination of eggshell and ceramic. In the presence of eggshell finer internal structure is observed which justify the maximum water absorption. Air voids are observed in both mixes, lower density and higher water absorption is justified.

6.2 Future Recommendation

Keeping in mind conclusions extracted from this research many future recommendations can be made. Following are the future recommendations on the basis of research work.

- The eggshell-incorporated mix, which comprises 15% of the eggshell powder, demands greater focus, particularly as we begin to decrease the ceramic content. Similarly, the replacement of cement with a combination of eggshells and other waste materials such as rice husk ash and marble powder require further validation to establish the broader concept of hybrid waste materials. By conducting comprehensive research in this area, we can gain a better understanding of the potential of these materials as sustainable alternatives to traditional cement.

- Chemical testing is recommended to validate the incorporation of eggshells and wheat straw in concrete. Such testing would offer valuable insights into the chemical reactions that occur when using these waste materials as sustainable alternatives to traditional concrete constituents. Moreover, the treatment of wheat straw fibers needs to be reviewed, as the results indicate that these fibers do not respond well to cement replacements. While both wheat straw and eggshells are chemically inert, proper treatment of the organic matter in fibers is essential for their effective use in concrete. By addressing these concerns, we can develop more sustainable and eco-friendly concrete alternatives.

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