CHAPTER 3 : MATERIALS AND CHARACTERIZATION

3.1 Introduction

Based on the limited existing literature, it can be determined that construction and demolition recycled fine aggregate (CD-RFA), ceramic waste tile powder (CWTP), water-to-cement ratio, and foaming agent dilution ratio significantly affect the strength, porosity, sorptivity, and durability properties of foam concrete (FC) mixtures. Nevertheless, the majority of the existing literature is predicated on the use of recycled waste materials and various supplementary cementitious materials exclusively at a singular dilution ratio of the foaming agent. The current study primarily aims to investigate the potential of varying percentages of CD-RFA aggregate as a substitute for natural river sand and ceramic waste tile powder (CWTP) as a replacement for cement in mix proportions, utilizing three dilution ratios of foaming agent for the production of FC mixes, while preserving a balance among porosity, density, sorptivity, and strength characteristics, and examining their effects on the aforementioned properties of the FC mixes. Furthermore, the impact of different dilution ratios of the foaming agent on the aforementioned properties of the FC mixture was evaluated. The current study also established relationships among strength, sorptivity, water absorption, and porosity of FC mixes. The findings of this study are expected to enhance the understanding of the relationship between varying percentages of CD-RFA and ceramic waste tile powder (CWTP) usage, thereby aiding in the rational design of an FC mixture in the future. The feasibility of the examined FC mixtures in hostile environments was investigated. The flow chart of chapter 5 and chapter 6 are shown in **Fig. 1** and **Fig. 2**.

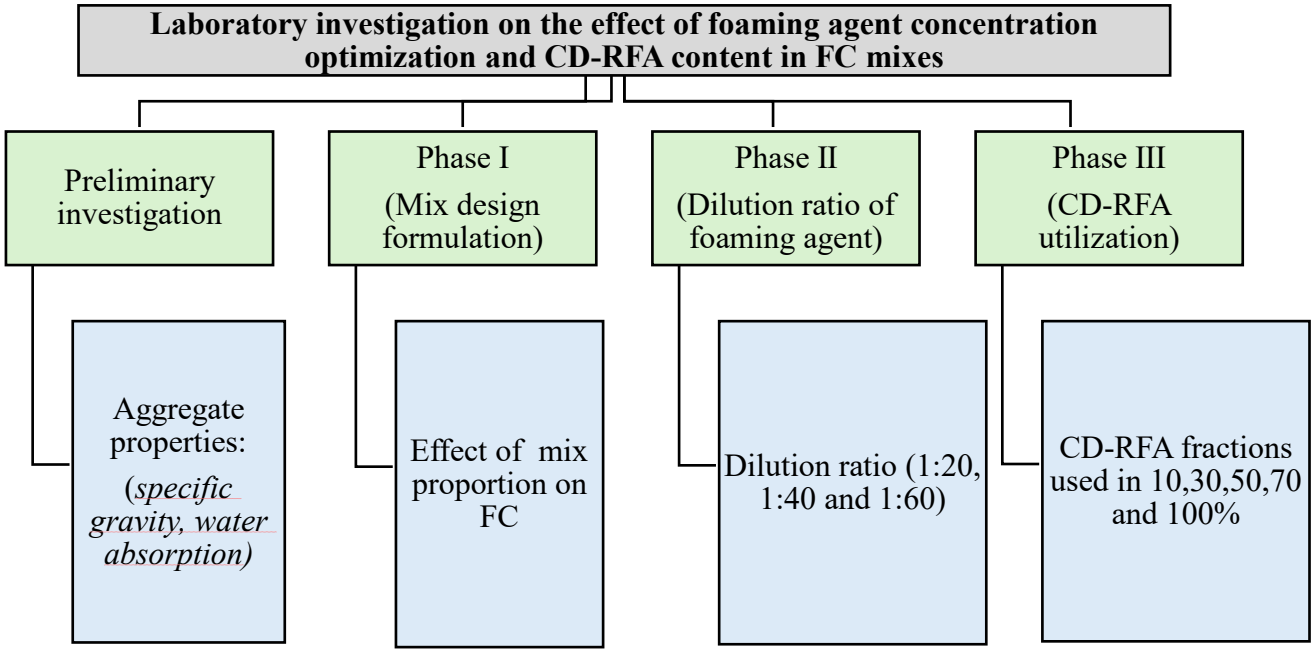


Fig. 1. Flowchart of methodology adopted in Chapter 5 of thesis.

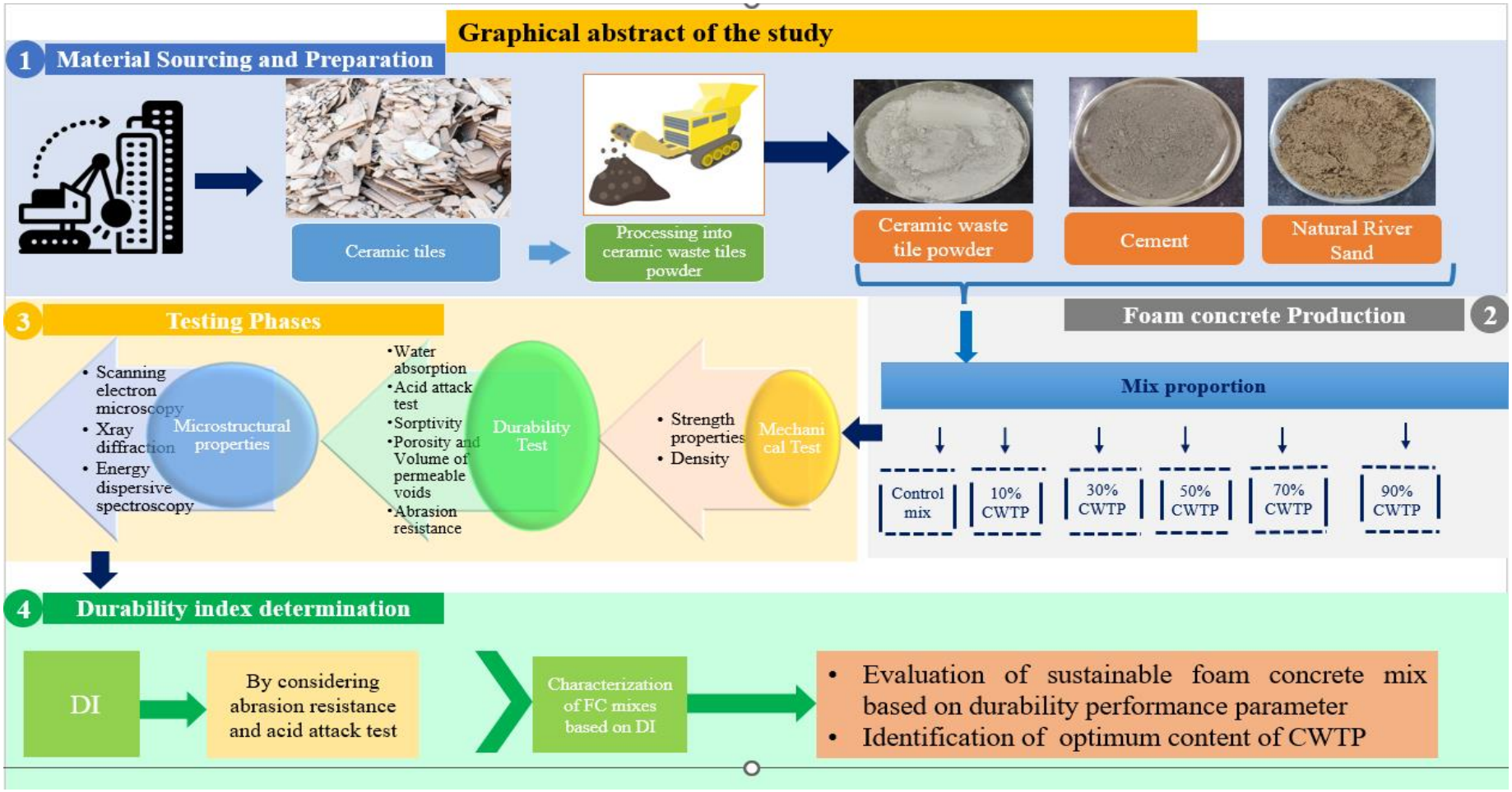
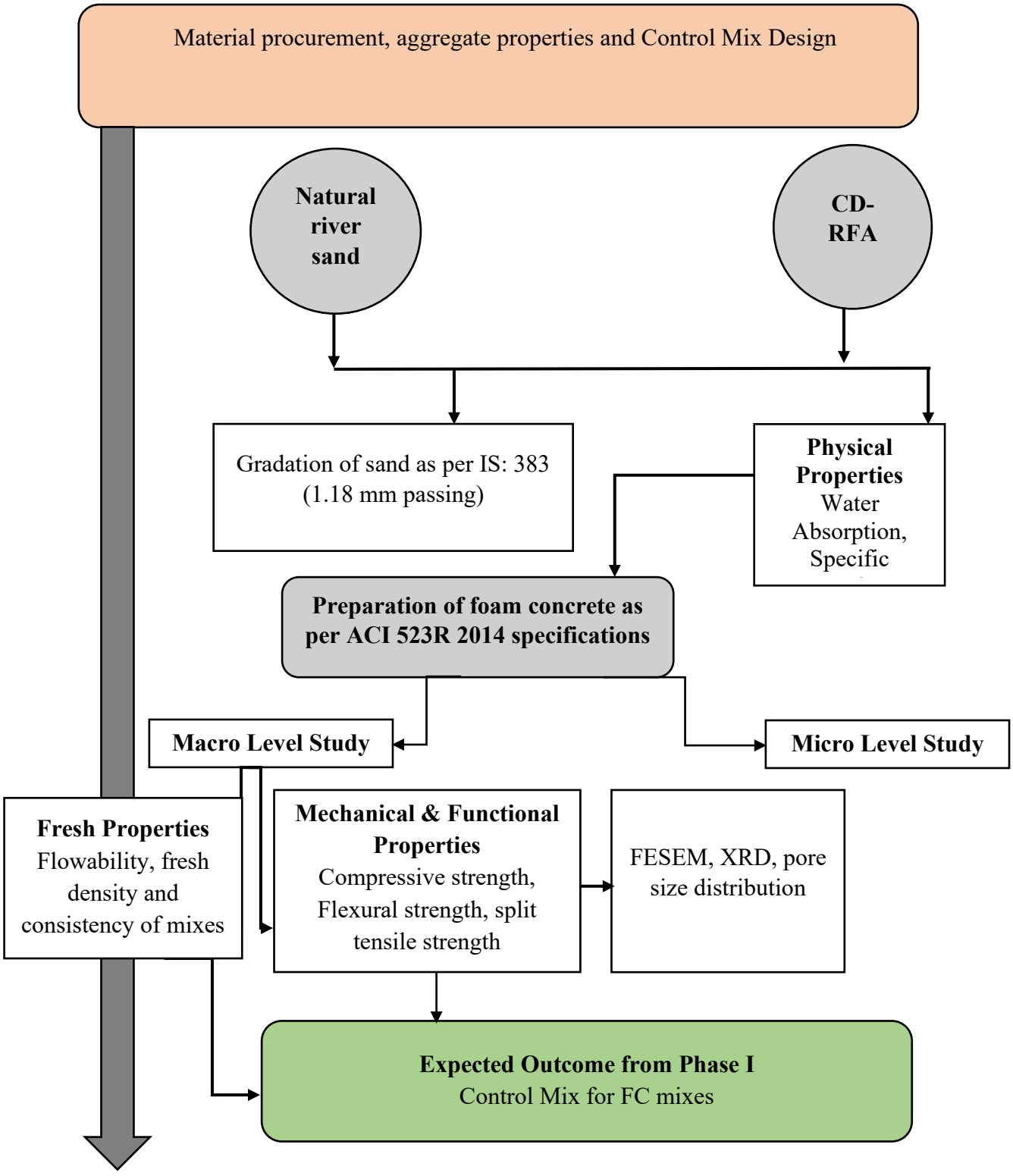
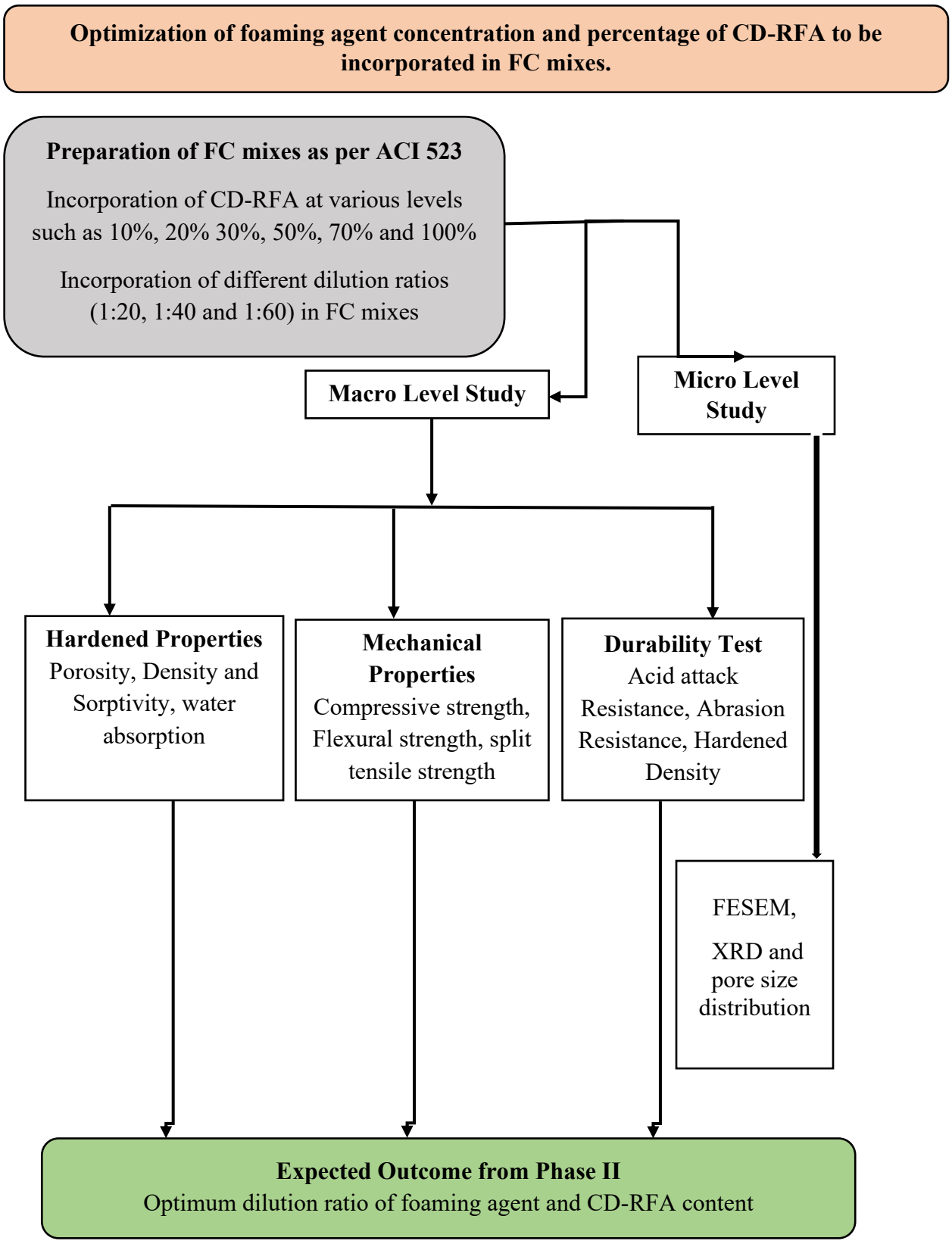


Fig. 2. Flowchart of methodology adopted in chapter 6 of thesis.

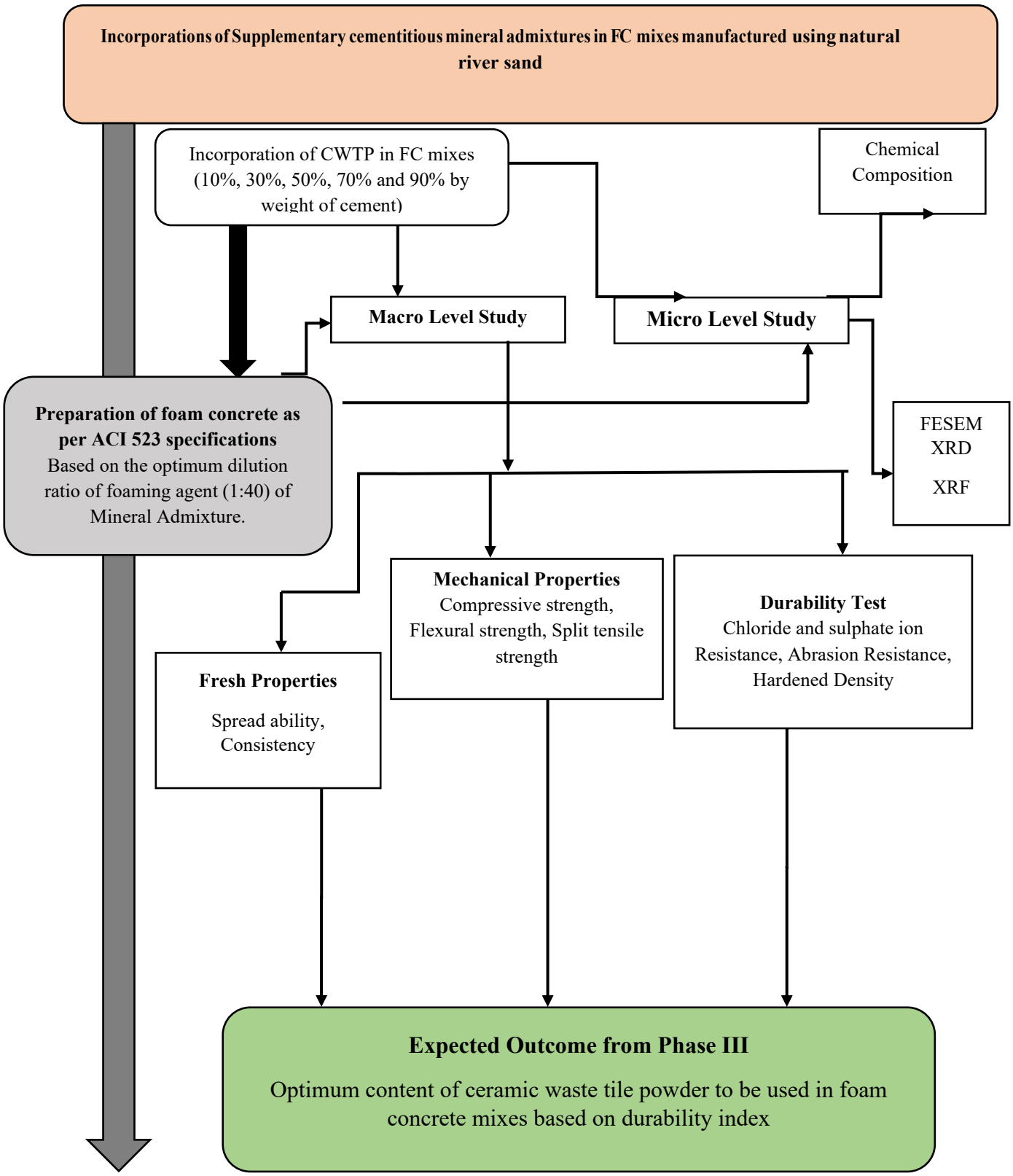
PHASE I


Material procurement, aggregate properties and Control Mix Design
Natural river sand
CD-RFA
Gradation of sand as per IS: 383 (1.18 mm passing)
Physical Properties Water Absorption, Specific
Preparation of foam concrete as per ACI 523R 2014 specifications
Macro Level Study
Micro Level Study
Fresh Properties Flowability, fresh density and consistency of mixes
Mechanical & Functional Properties Compressive strength, Flexural strength, split tensile strength
FESEM, XRD, pore size distribution
Expected Outcome from Phase I
Control Mix for FC mixes

PHASE II


Optimization of foaming agent concentration and percentage of CD-RFA to be incorporated in FC mixes.
Preparation of FC mixes as per ACI 523
Incorporation of CD-RFA at various levels such as 10%, 20% 30%, 50%, 70% and 100%
Incorporation of different dilution ratios (1:20, 1:40 and 1:60) in FC mixes
Macro Level Study
Micro Level Study
Hardened Properties
Porosity, Density and Sorptivity, water absorption
Mechanical Properties
Compressive strength, Flexural strength, split tensile strength
Durability Test
Acid attack Resistance, Abrasion Resistance, Hardened Density
FESEM,
XRD and pore size distribution
Expected Outcome from Phase II
Optimum dilution ratio of foaming agent and CD-RFA content

PHASE III


Incorporations of Supplementary cementitious mineral admixtures in FC mixes manufactured using natural river sand
Incorporation of CWTP in FC mixes (10%, 30%, 50%, 70% and 90% by weight of cement)
Chemical Composition
Macro Level Study
Micro Level Study
Preparation of foam concrete as per ACI 523 specifications
Based on the optimum dilution ratio of foaming agent (1:40) of Mineral Admixture.
FESEM
XRD
XRF
Mechanical Properties
Compressive strength, Flexural strength, Split tensile strength
Durability Test
Chloride and sulphate ion Resistance, Abrasion Resistance, Hardened Density
Fresh Properties
Spread ability, Consistency
Expected Outcome from Phase III
Optimum content of ceramic waste tile powder to be used in foam concrete mixes based on durability index

3.2 Materials Testing

3.2.1 Natural river sand and CD-RFA

The aggregate physical and microstructural qualities are considered to indirectly influence the ultimate strength of concrete, requiring characterization. This research examines specific gravity, water absorption, and density as key physical parameters. The specific gravity, water absorption, and density of the aggregates were determined in accordance with IS: 2386-III [55]. In addition to the physical and mechanical properties of the aggregates, petrographic analysis was conducted on the natural and recycled fine aggregates in accordance with IS: 2386-VIII [54] to ascertain their parent rock composition.

3.2.2 Cementitious and supplementary sementitious materials

A Le-Chatelier apparatus was used to measure the specific gravity of Portland cement, and the test was conducted in accordance with IS:4031-I [143]. The consistency of Portland cement was assessed using a Vicat apparatus compliant with IS:4031-IV specifications [144]. The cement curing time was also evaluated using a Vicat apparatus, following IS: 4031-V [145]. The specific surface area of the pozzolans was measured using Blaine air-permeability apparatus in compliance with ASTM C204 [146]. The loss of ignition and moisture content in the ceramic waste tile powder (CWTP), employed in this thesis were assessed using ASTM D7348 [147] standards.

3.2.3 Potable water

Water used for the mixing of experimental investigations in accordance with ASTM C1602 [148] (ASTM 2018b).

3.2.4 Natural protein based foaming agent

The quality of foam is essential for the stability of foamed concrete and influences the strength and stiffness of the final product. Consequently, high-quality foam (35-45 kg/m³) was generated by combining the protein based foaming agent in water make apparatus which combines them with air to form foam at three different dilution ratios, i.e., 1:20, 1:40, and 1:60 (1 part foaming agent to 20 parts of water).

3.3 Testing of foam concrete mixtures

3.3.1 Fresh state characteristics

To determine the stability of foam concrete mixes, the fresh density was determined by filling a standard container of known volume, and the density ratio was computed by comparing it to the design density. The spread ability was assessed using the ASTM standard flow cone, ASTM C230 [146]. Upon filling the cone with the mixture, it was elevated, and the average concrete flow was assessed without any abrupt movements of the flow table, as such disturbances could influence the entrained air bubbles. The spread flow of concrete was quantified as a percentage of the cone's base diameter and assessed for various mixture compositions. The fluidity of the mixtures was assessed via the modified Marsh cone test [72].

3.3.2 Mechanical characteristics

This thesis investigates the compressive strength, split tensile strength, and flexural strength as the strength characteristics. The compressive strength of hardened FC specimens, subjected to wet curing for 7, 28, and 90 days, was assessed using a compressive testing machine. The compressive block specimens measured 100 mm x 100 mm x 100 mm (length x breadth x height). In compliance with IS:516, the compressive strength was cast and evaluated [149] (BIS 1959). The splitting tensile strength and flexural strength tests were conducted on cylindrical (100 mm x 200 mm) and prism (500

mm x 100 mm x 100 mm) specimens with exact dimensions. The specimens underwent a curing process in water at ambient temperature for a specified duration, as per the guidelines outlined in IS 516–1959 [149].

3.3.3 Durability characteristics

The durability parameters considered for evaluation in this thesis are density, porosity, water absorption, sorptivity, abrasion resistance, chloride attack, and sulfate attack, respectively.

3.3.3.1 Abrasion resistance

The functional performance of foam concrete mixtures is compromised by deterioration caused by abrasive forces. Consequently, if FC mixtures are to be utilized as a surface layer, they must undergo evaluation. FC specimens were fabricated and evaluated according to the ASTM C1747 [150] standard for assessing the abrasion resistance of the specified mixes. This study utilized a normal Los Angeles abrasion machine (without steel balls) to evaluate the mass and strength loss resulting from abrasive forces after 28 days of standard curing. To assess the abrasion resistance of the FC mixes in question, cylinders measuring 100×200 mm of each mix were cast and cured. Three specimens (excluding steel balls) were positioned in the Los Angeles abrasion machine and rotated at 33 rpm for approximately 15 minutes each. Prior to placing each cube into the Los Angeles machine, the original mass of each cube was documented. The specimens were cleansed of any loose debris following 500 revolutions, and the mass was documented. Equation 3.1 is utilized to calculate the mass loss resulting from Cantabro abrasion. The compressive strength of these cubes was concurrently evaluated according to IS:516 (BIS 1959) standards. The compressive strength of the remaining three cubes was determined, utilizing Equation 3.2 to determine the strength loss during standard curing days.

Cantabro Loss in mass (%) = (*Initial mass – Final mass*) / *Initial mass* X 100 (*3.1*)

Cantabro Loss in Strength = ($CS_1 – CS_2$) / CS_1 X 100 (*3.2*)

Where CS_1 = original compressive strength at 28 days of normal curing and CS_2 = compressive strength after abrasion at 28 days of normal curing.

3.3.3.2 Density, porosity and volume of permeable voids

The density, water absorption, volume of permeable voids, and porosity of FC mixes including CD-RFA were evaluated using cube specimens of 100 × 100 × 100 mm. The specimens underwent a curing process in water for a duration of 28 days, in accordance with the parameters specified in ASTM C642 [151].

Density plays a crucial role in determining the physical, mechanical, and durable properties of foam concrete. The wet/plastic density of foam concrete mixes was calculated as per ACI 523 R-14 [152], and the dry density, bulk density, and apparent density of FC mixes were determined based on ASTM C642[151]. The density of foam concrete depends on various factors like the amount of foam, fine aggregate size, type of filler used in the mixture, and plastic density, which decreases as the foam amount increases. The wet/plastic density of foam concrete mixes is an indicator of the foaming amount in mixes. Its wet/plastic density is responsible for providing the proper volume required for the design mix and managing the pouring process, whereas its dry density affects the material's mechanical, physical, and durability characteristics. Dry density depends on how much foam is used in the wet mixture, and the volume of the fresh wet mixture increases with an increase in foam quantity.

The porosity and volume of permeable voids of foam concrete are calculated in accordance with ASTM C642 [151]. Both properties of foam concrete affect the mechanical and durability properties of FC mixes. Water ingression in FC mixes depends

on porosity, the diameter of capillary pores, pore distribution, connectivity of pores, and integrity of the mix. Many parameters, including porosity, permeability, pore size, and pore dispersion within the material, can affect the physical properties of cement-based materials, such as their strength and durability. Three different types of porosity—gel pores, capillary pores, and air pores—usually make up the pore structure of foam concrete. Gel pores have little effect on the strength of foam concrete; instead, capillary and air gaps affect the material strength. The distribution and size of foam concrete pores directly affect the mechanical and physical properties of foamed concrete. Therefore, the properties of the porous structure are quite important when discussing foamed concrete. The higher the volume of permeable void concentration, the larger the porosity of the concrete mixes, which would eventually allow acidic ions from neighboring environments to infiltrate, causing durability difficulties. As a result, th e ASTM C642 (ASTM 2006) [151] tested parameters of 110°C for 24 hours. Following that, using

Equations. (3.3) and (3.4), the porosity and density of the FC specimens were computed.

$$Porosity\ (\%) = (C - A) / (C - D) \text{ X } 100 \qquad (3.3)$$

$$Density\ (kg/m^3) = A / (A - D) \text{ X } 100 \qquad (3.4)$$

$$Water\ absorption\ (\%) = (B - A)/A) \text{ X } 100 \qquad (3.5)$$

Where A is the oven-dried mass of the specimen (g), B is the SSD mass of the specimen after immersion (g), C is the SSD mass of the specimen after immersion and boiling test (g), and D is the mass of the specimen in water after immersion and boiling test (g).

3.3.3.3 Chloride and sulphate attack

When exposed to harsh environments, concrete pavements become prone to physical and chemical damage by sulfate and chloride ions, necessitating examination. To test the effect of hardened FC mixes positioned in an aggressive environment of

sulfate- and chloride-rich ions, 100 mm cubes were made according to ASTM C267 (ASTM 2012b) [153] and cured for 28 days. Acidic solutions of hydrochloric acid (HCl) and sulfuric acid (H_2SO_4) were created with a concentration level of 2% each to replicate the adverse environmental conditions in the laboratory. Three specimens from each FC combination were stored in separate acid solution tanks (HCl and H_2SO_4). After that, following 28 days of normal curing, another set of three specimens was examined for compressive strength. To maintain a steady acidic concentration level throughout the trial, the acidic solutions were replaced every 14 days. The specimens were subjected to severe acidic solutions for 56 days before being withdrawn from the solution tanks, washed with potable water, cleaned with cotton cloth, and their saturated surface dried (SSD) weight recorded. The specimen's compressive strength was tested immediately after exposure to an acidic environment, according to IS:516 (BIS 1959). To determine the variation in the average compressive strength of the FC specimens after exposure to aggressive ions, the remaining specimens that had been cured for 56 days in a regular curing tank were removed, brought to SSD state, and their individual compressive strength was documented. The mass loss and compressive strength of hardened FC mixtures exposed to an acidic environment are calculated using the equations below.

$$\text{Change in mass (\%)} = ((SSD1 - SSD2) / SSD1) \text{ X } 100 \quad (3.7)$$

$$\text{Loss in compressive strength (\%)} = ((C1 - C2) / C1) \text{ X } 100 \quad (3.8)$$

Where SSD1 is the initial mass of the specimens (g), SSD2 is the mass of the specimens after exposure to acidic solutions (g), C1 is the compressive strength of specimens tested at 28 days of normal curing, and C2 is the compressive strength of specimens tested after exposure to acidic solutions (MPa).

3.3.4 Microstructural investigation

3.3.4.1 Scanning electron microscope

A Scanning Electron Microscope (SEM) was used to examine the microstructure around the ITZ and air spaces. To remove evaporable water, fractured specimens of about 10 mm thickness were carefully picked from all the hardened FC specimens and heated in an oven for about 24 hours at 105 ± 5°C. The specimens were then sputter-coated and placed on metal stubs before being exposed to an electron beam from SEM. At various magnification levels, images were scanned at a 20 kV accelerating voltage. Using image processing software (ImageJ), the size and area of voids in the surface morphology of the specimens were calculated.

3.3.4.2 X-Ray diffractometer

XRD analysis was used to investigate the crystalline phases in the concrete. Using about 1 gram of powdered specimens from 28-day-old foam concrete was processed to detect the crystalline phases. The powdered specimens were scanned at a speed of 6 θ/min from 5 θ to 90 θ at an angle of 2 θ, resulting in a substantial diffracted peak. Each prominent peak in the specimen corresponds to a unique crystalline phase. According to Bragg's law, the spacing of the crystallographic planes determines the position of these peaks (Equation 3.9). Using the software Xpert High Score Plus, the phases corresponding to the diffracted peaks were then detected.

$$n\lambda = 2d \sin \theta \qquad (3.9)$$

where λ = wavelength of the x-ray, d = spacing of the crystal layers, θ = *incident* angle, and n = integer

3.3.5 Formulation of mix design

The mix design was formulated in accordance with ACI 523 R-14 [152] guidelines.

The formulation of the FC mix design consists of seven steps:

1) Fixing Target Density
2) Fixing w/c ratio
3) Selection of cementitious content
4) Selection of natural river sand (size passing from 1.18 mm sieve)
5) Foaming agent
6) Casting samples to measure compressive strength
7) Calculate the mixture proportions

Data required for mix proportioning

- Target Density
- Type of cement (Grade of cement)
- Fixing w/c ratio
- Maximum nominal size of fine aggregate (passing from 1.18mm sieve)
- Recycled fine aggregates from construction and demolition (CD-RFA)
- Ceramic waste tile powder (CWTP)
- Foaming agent at 1:20, 1:40, and 1:60 dilution ratio (1 part of foaming agent in a liter and 20 parts of water in a liter, respectively).

Calculate the mix proportions: After the final selection of the cementitious content and mix content, the final mixture proportions were calculated in this thesis. W/C of 0.55 was used based on flowability test. It was observed that the use of super plasticisers and water reducers agents negatively affects the formation of entrained air in case of natural protein

based foaming agent into foam concrete. Because of this reason none of the past studies have used superplasticiser or chemical admixtures in foam concrete. Further, use of entrained air in concrete helps in improving workability. Workability is also improved by chemical admixtures. This may be the reason why past studies have resorted to entrained air in foam concrete and avoided use of chemical admixtures in foam concrete.

3.3.6 Mix design

For all the FC mixtures, a mixing time of around 8 minutes was maintained throughout the laboratory experiment. The following is the FC mixing procedure: 2-3 minutes for fine aggregates, cementitious materials/pozzolanas, 2 minutes for water, and 1-2 minutes for foaming agent. The mixes were then put in molds and after 24 hours of pouring specimens were carried out with the forhardened testing of FC mixes.

3.4 Selection of natural river sand and CD-RFA aggregates

River sand passing 1.18 mm IS sieve was used. It was sourced from chopan in Son Bhadra district of UP in India. Prior to casting, the sand particle undergoes a thorough oven-drying process at a temperature of 105°C for a duration of 24 hours to eliminate any moisture. The gradation curve is shown in **Fig. 4**. The physical properties of the natural river sand were analyzed in line with IS 2386 [54,55] and are shown in **Table 1.**

The CD-RFA was sourced from Prayagraj Municipal Corporation, Prayagraj, India. Acquired CD-RFA acquired had an age of less than 6 months infested with dust due to open storage practice. Therefore, it was subjected to ordinary washing and drying for duration of 24 hour in an oven at 100–105 °C. Subsequently, it was sorted into suitable binary gradation with a range of 1.18 mm. The CD-RFA was utilized without any additional processing in FC mixes. Photographs of CD-RFA and sand used is shown in

Fig. 3 a) and **Fig. 3** c) , while their SEM images (25000 x) in **Fig. 3** b) and **Fig. 3** d). The SEM of CD-RFA illustrates the consistent distribution and size of particles. The particles closely resemble the shape and size of river sand. Additionally, CD-RFA aggregates possess rough surfaces characterized by the presence of small particles and micro cracks. They exhibit a greater degree of surface irregularity in comparison to natural river sand. Natural river sand exhibits well-graded particle size distribution, with a smooth surface, resulting in a more consistent aggregate size. On the other hand, CD-RFA exhibits an inferior dispersion characterized by a deficiency of particles of intermediate size, resulting in an uneven classification that might have an impact on the quality of foam concrete. In the XRD investigation, recycled fine aggregates (CD-RFA) and natural river sand differ greatly in composition. Quartz (SiO_2) peaks at 26° in river sand indicate crystalline quartz. River sand contains significant quartz content because it is formed of old and degraded silicate minerals. CD-RFA has less quartz and more feldspar, calcium carbonate and calcium silicate. Crushed masonry, tiles, mortar, cement paste, and ceramic debris from building and demolition make up CD-RFA. Strong and fireproof ceramic tiles and bricks include feldspar. CD-RFA indicates tile or brick debris in aggregate. $CaCO_3$ is a product made from carbonated cement paste, plaster, or concrete, which contain calcium compounds that carbonate over time. The presence of C_2S (belite) in crushed concrete debris indicates unhydrated or partially hydrated cement particles. The physical properties of the Natural River Sand and CD-RFA were analyzed in line with IS 2386 [54,55] and are shown in **Table 1** and chemical composition of CD-RFA is shown in **Table 2**.

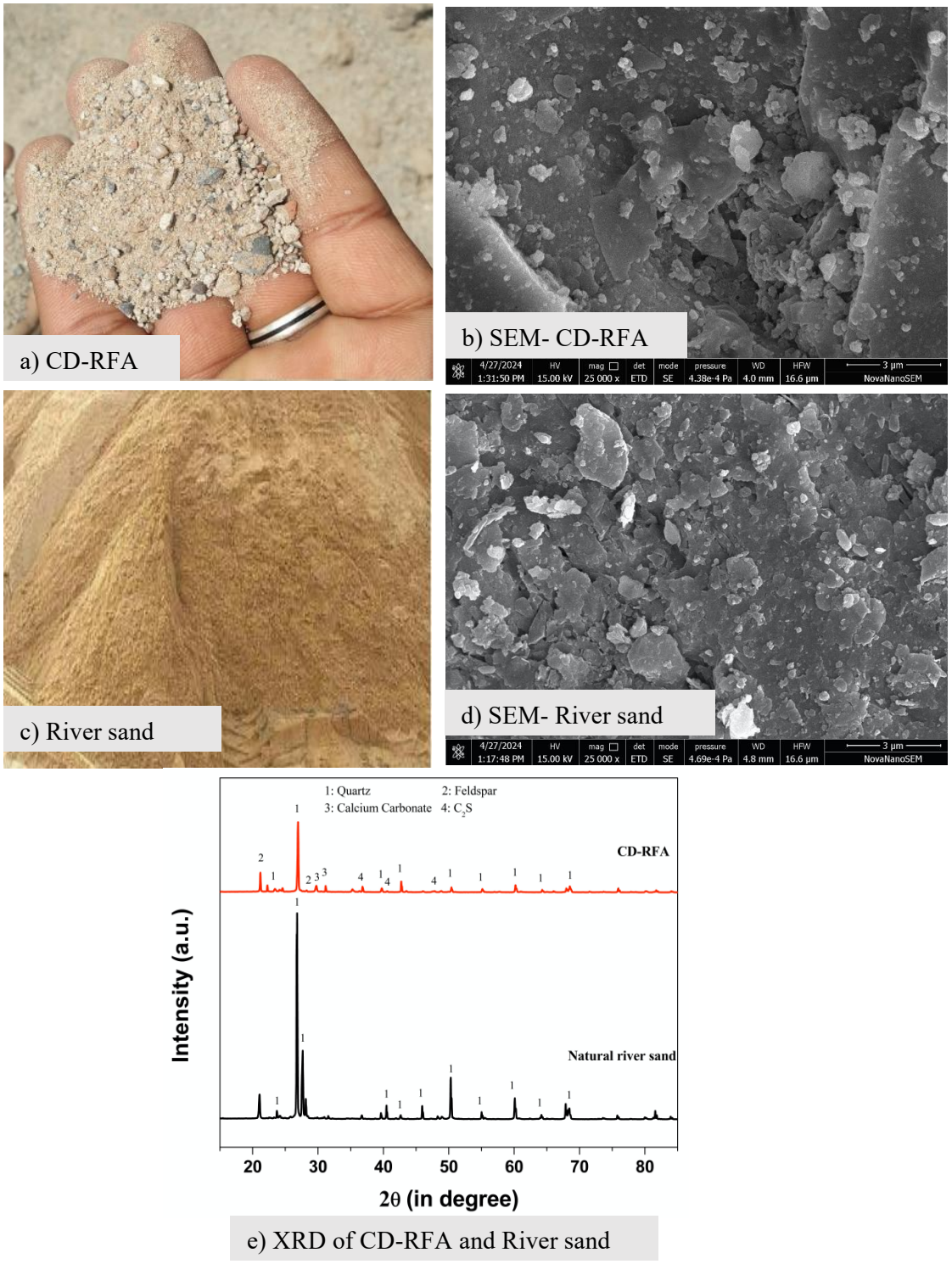


Fig. 3. a) Photograph of CD-RFA used in the present study b) SEM image of CD-RFA at 25000x c) Photograph of natural river sand d) SEM image of natural river sand at 25000x e) XRD of CD-RFA and natural river Sand.

3.5 Particle size distribution of natural river sand and CD-RFA aggregates

Dry natural river sand was dried at 100-105 °C for 24 hr and sieved using a 1.18 mm sieve and has gradation as shown in **Fig. 4**.

C&D waste was subjected to hand sorting post-unloading to eliminate impurities or cross-contamination, including glass, textiles, wood, twigs, etc., via visual inspection. Larger fragments were manually reduced. Later, they were washed to eliminate contaminants and dust. The processed construction and demolition waste fraction is typically regarded as comprising predominantly inert, coarse particles of different sizes. Nonetheless, the XRD analysis indicated the existence of hydrated or partially hydrated belite within the construction and demolition waste. It is essential to emphasize that while most of the particles are inert, the existence of certain reactive phases like belite suggests that the waste is not entirely made up of inert materials. Size finer than 1.18 mm sieve and coarser than 75 µm. The gradation curve of sand reveals well-graded sizes, while that of CD-RFA falls above the upper gradation limits (size less than 0.6 mm). Below this, particle sizes fall within the gradation limits [154].

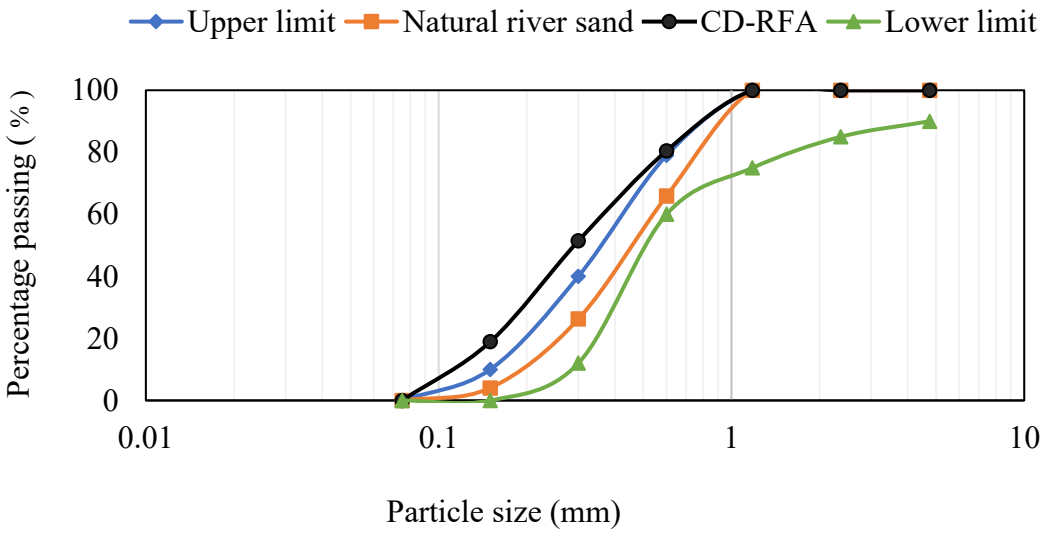


Fig. 4. Gradation of river sand and CD-RFA passing 1.18 mm sieve.

3.6 Aggregate properties

Table 1 delineates the physical characteristics of natural river sand and CD-RFA aggregates. Because cement paste or mortar from old concrete is mixed in with CD-RFA aggregates, their specific gravity may be lower than that of natural aggregates. The mortar encasing the aggregate particles also helps in specific gravity. The mortar frequently exhibits greater porosity than the natural aggregate, resulting in heightened water absorption. Increased porosity indicates a greater number of voids within the material, thereby reducing its effective density [86,135,138]. These factors affect their physical properties of concrete applications. Increased water absorption may require modifications to the water content during mixing to attain optimum workability. When concrete is made with recycled aggregates instead of natural aggregates, the mechanical properties may be different, which can sometimes lower the compressive strength.

Table 1: Physical properties of aggregates

Properties	River sand	CD-RFA	Standard code followed
Fineness modulus	3.0	2.49	IS 383: 1970
Coefficient of uniformity	2.76	3	IS 383: 1970
Coefficient of curvature	1.059	0.94	IS 383: 1970
Specific Gravity	2.632	2.463	IS 383: 1970
Water absorption (%)	1.2	2.85	IS 2386: 1963

3.7 Cementitious materials

The primary binding material used was Ordinary Portland cement (OPC) grade 53 that conformed to IS: 12269 [155] (BIS 2013). Ceramic waste tile powder (CWTP) was used for partial replacement of OPC to reduce its consumption. Ceramic tiles are often discharged in an open environment. However, they contain reactive silica, and hold

promises for partial replacement of OPC due to their propensity to foster secondary pozzolanic reaction. The ceramic tiles waste was sourced from the Rajkot (India) and crushed into smaller fragments using a jaw crusher. It was further fragmented using a pulverizer and then transformed into a powder in a ball mill. Powdered ceramic was used as a replacement for cement. Use of ceramics in powder form is ideal because they possess properties similar to cement and do not compromise the strength of concrete [60]. **Table 2** provides information regarding the chemical composition of ceramic waste tile powder.

Table 2: Chemical composition of materials used in study

Compound	CD-RFA	OPC 53	CWTP
SiO_2	71.038	22.22	60
TiO_2	0.261	0.12	-
Al_2O_3	7.162	5.90	33.90
Fe_2O_3	2.263	2.185	0.56
Mn_3O_4	0.051	-	-
MgO	1.015	2.57	1.54
CaO	7.467	61.15	1.68
Na_2O	0.926	0.15	-
K_2O	1.85	0.12	0.47
P_2O_5	0.063	0.16	-
SO_3	0.137	3.2	0.85
V_2O_5	0.01	-	-
Cr_2O_3	0.009	-	-
SrO	0.013	-	-
ZrO_2	0.014	-	-
BaO	0.046	-	-
NiO	0.004	-	-
CuO	0.004	-	-

ZnO	0.014	-	-
PbO	0.006	-	-
MnO	0.047	0.025	

A pozzolanic reaction requires the presence of CaO and SiO_2, whereas the presence of reactive SiO_2 in the SCMs is required for the secondary pozzolanic reaction to occur. **Table 3** show that all the values are within the permitted limits set out in ASTM C618 (ASTM 2019b).

Table 3: Physical properties of cement and pozzolans

Property	Portland cement	CWTP
Specific Gravity	3.15	2.22
Blaine's fineness, cm^2/g	3363	20000
Consistency	30	-
Initial setting time (min)	53	-
Final setting time (min)	309	-
Loss of ignition (%)	1.24	2.20
Moisture content (%)	0.1	0.25

3.7.1 Characterization of ceramic waste tiles powder

The SEM images of the CWTP material were done at different magnifications and exhibited in **Fig. 5**, the particles of irregular and angular type that were like cement. Table 1 displays the chemical composition of the CWTP as determined by X-ray fluorescence (XRF). The results showed that CWTP primarily contained silica (SiO_2) and alumina (Al_2O_3). Around 93 % of the total material mass was found in both oxides. The higher percentages of silicate and aluminate in the CWTP material may help in pozzolanic reactivity. The mass fractions of (SiO_2 +Al_2O_3+Fe_2O_3) in the CWTP met the specified requirement in ASTMC618 [34] for natural pozzolana, which is 70 %.

Additionally, trace amounts of various oxides, including Fe_2O_3, CaO, MgO, and SO_3, were found in the CWTP. In addition, the SO_3 and LOI met the requirements of ASTM C618 [34]. Based on its mineral composition, CWTP qualifies as a pozzolana material. X-ray diffraction analysis was used to examine the mineralogical configuration of CWTP. **Fig. 5** shows the XRD analysis of the CWTP. The XRD analysis showed clear peaks between 2-theta values of 20° to 30°, indicating the presence of (SiO_2). There appears to be a hump between 20° to 30°, 50° and 65° to 70° suggesting the presence of an amorphous phase in the CWTP. In addition, the uneven graph trend from 5° to 80° in the 2-theta values could potentially suggest the presence of an amorphous phase in the CWTP sample. Comprehending the characteristics and possibilities of pozzolans, regardless of whether they are naturally occurring or produced as industrial by-products, is an intricate undertaking inside the field of cement and concrete. Standards and prior investigations have placed significant importance on strength as the primary criterion for evaluating pozzolanic activity. Based on the initial evaluation described in ASTM C618 [34], the combined amount of SiO_2 + Al_2O_3 + Fe_2O_3 obtained from the XRF study surpassed the 70 % limit. Therefore, the CWTP material was considered pozzolana material, and its effect on the strength development was evaluated using the strength activity index (SAI) test following the requirements of ASTM C311 [35]. The strength activity index was determined by calculating the percentage of strength at 14 days compared to the control mix that does not contain CWTP. Error! Reference source not found. **Table 4** presents strength, standard deviation, and strength activity index (SAI). ASTM C618 states that SAI values above 97 % after 28 days indicate a positive pozzolanic action. The findings demonstrated that all CWTP specimens fulfilled the SAI criterion of ASTM C618 [156]. It was noted that as the replacement level climbed to 40 %, the influence of CWTP became more noticeable, and the SAI value exceeded 91 % at

14 days testing [157]. The results indicated that CWTP exhibited a composition high in silica and alumina, along with the presence of certain amorphous phases. The strength development evaluation shows that the CWTP may have some pozzolanic activity. Thus, CWTP can replace cement as a substitute ingredient in concrete mixtures. The assessment of the performance of different foam concrete mixtures that included CWTP with varying replacement levels was necessary.

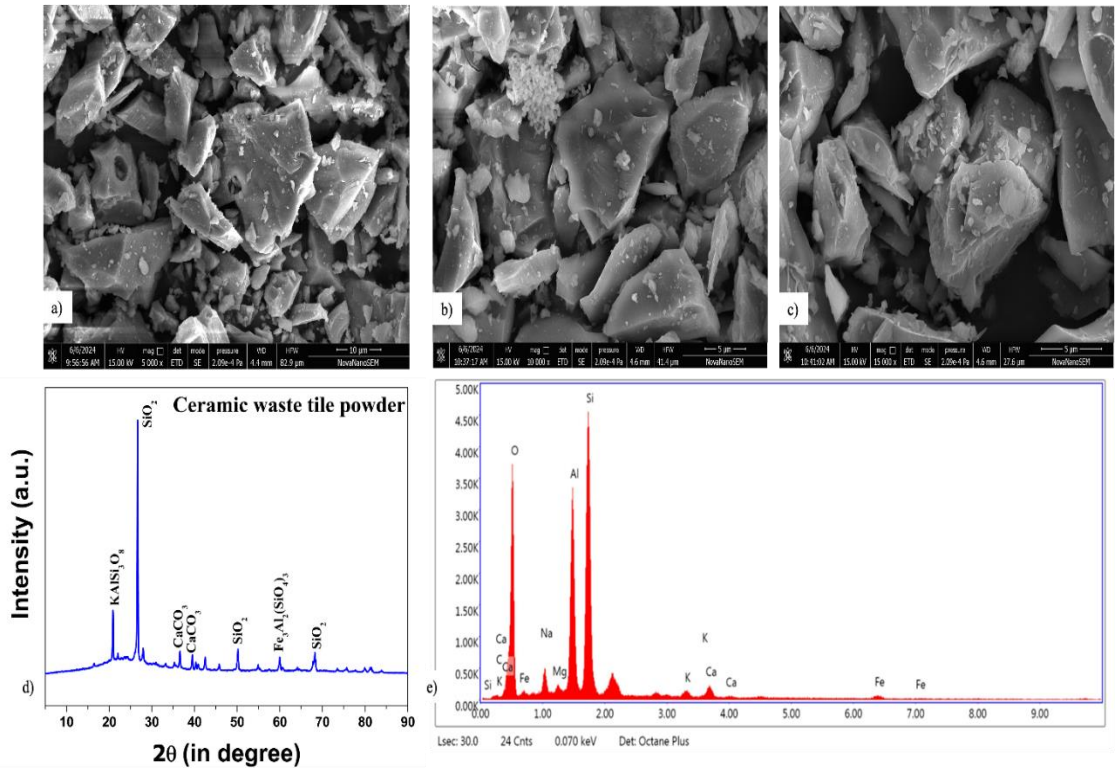


Fig. 5. SEM, XRD and EDS of CWTP.

Table 4: Strength Activity Index of mortar mix admixed with CWTP

Compressive strength (MPa)	CWTP replacement level (by mass)			
	7 days		14 days	
	20%	40%	20%	40%
Average compressive strength (MPa)	29.6	27.47	34.01	32.01
Standard deviation (MPa)	1.06	1.404	0.40	1.44
Strength activity index (SAI) in %	95.61	88.72	97.70	91.95

3.8 Foaming agent

Foam is the key component of foam concrete, and the production of this foam relies on the use of foaming agents [79]. The influence of foaming agents on the density, porosity, stability, and fluidity of foam concrete is significant. The primary objective is to incorporate air bubbles into concrete. Foam can be generated through two distinct approaches: the pre-foaming method and the mixed foaming method.

Foaming agents encompass a variety of types, including synthetic materials, glue resins, protein-based substances, detergents, resin soaps, saponins, and hydrolysed proteins. Nonetheless, the foaming agents that are most frequently utilized are those that are either synthetic or derived from proteins [158,159]. Protein-based agents facilitate a more robust pore structure and a denser void space network. A more stable air-void network is established. Synthetic agents, conversely, facilitate greater expansion, resulting in lower densities. Synthetic agents demonstrate greater cost-effectiveness and user-friendliness compared to protein agents, while also necessitating reduced energy for storage [160–162]. Falliano et al. [66] observed that maintaining a consistent water/cement ratio led to foam concrete samples that exhibited greater stability compared to those derived from protein sources. Ranjani and Ramamurthy [159]conducted an analysis of the foam generated with sodium lauryl sulphate (SLS) as the surfactant. The foam generated using SLS was unable to retain the liquid within it, resulting in a 40% decrease in density immediately after its production. It was also observed that with an increase in the dilution of SLS, there is a corresponding increase in drainage.