CHAPTER THREE

PROPOSED METHODOLOGY

3.1. Research Design

This study will adopt investigate the effect of hydrogen peroxide (H_2O_2) as a foaming agent and the addition of stone dust as a coarse aggregate on the durability of hybrid foam concrete (HFC) under different curing conditions. The study will aim to assess the following durability properties:

- Compressive strength
- Freeze thaw resistance
- Water absorption
- Shrinkage behavior
- Porosity

Compressive strength

Compressive strength is affected by parameters such as density, mixture components used, aggregate, mineral additive, water content, foam, curing and porosity. The amount of water has a significant effect on the compressive strength of foamed concrete. It was reported that small changes in the water content of foam concrete do not affect the strength as in normal concrete [`Ramamurthy, K et al (2009)]. An increase in the w/c ratio can provide an increase in strength. The reason for this can be demonstrated by the formation of pores that grow with the amount of water. With the increase in large pores and capillary pores, the density of the air voids decreases and the strength increases [Jiang, J.et al 2016]. Liu et al. reported that the compressive strength of foam concrete showed an inverted V-shaped change with the increase in the water/cement ratio. If the w/c ratio is below the optimal limit, thinner-walled and irregular foams occur, and the compressive strength is negatively affected. The use of the w/c ratio above the optimal limit results in a poorer bubble holding ability. It causes pores to join and uneven distribution. This irregularity in the pore structure is subjected to stress concentrations. In addition, the increase in the amount of water triggers the formation of capillary channels, thereby reducing its strength [Hashim, M et a]. The use of superplasticizer contributes to the increase in compressive strength by reducing the w/c ratio .

The aggregate type used is effective on the strength. Gencel et al. used RCA that increased the porosity, and this situation caused a decrease in the compressive strength. Similarly, Pasupathy et al. used RCA in geopolymer foam concrete. RCA content reduced compressive strength. This is because the strength of RCA particles is lower than sand. In addition, adding more water to obtain workability in RCA samples also negatively affected the strength.

Thanks to the pozzolanic properties of FA, its use in foam concrete as fine aggregate contributes to the compressive strength. Ramamurthy and Nambiar's study investigated the effect of the additive type on the compressive strength of foam concrete. The compressive strength of the samples using FA as filler material showed higher compressive strength values than those prepared with sand. Due to the late pozzolanic reaction of FA, the increase in compressive strength continues with the advancing age. When FA was used as filler, it was reported that the compressive strength of foam concrete was 1.7 and 2.5 times higher on the 56th and 180th days compared to the 28th day [Tikalsky, P.J et al (2004)].

The use of mineral additives affects the compressive strength. The use of silica fume in foam concrete increases the compressive strength. Compressive strength in soil-based foam concrete increased with the use of silica fume and quicklime. It was reported that it increased from 4 MPa to 7.8 MPa with the addition of 20% silica fume. This may be thanks to the finer pores caused by silica fume [Cong, M et al (2015)].

In the study of Bing et al, the 7-day compressive strength of samples containing FA showed 85–90% of the 28-day compressive strength. In samples without FA, this rate decreased to 75–80%. The compressive strength of the geopolymer foam concrete prepared with the addition of FA reached 7.5 MPa in 28 days. With the addition of 20% slag to FA, the compressive strength increased to 12.6 MPa. However, adding more slag slightly reduced the compressive strength [Zhang, Z et al (2016)].

Additives added to foam concrete affect strength. It is obvious that the superplasticizer causes higher strengths thanks to the lower void size and pore connectivity. Using SA reduces pore size. For this reason, the increase in dosage causes the strength to decrease [Jiang, J et al (2016)].

Comparing foamed and non-foamed samples, as expected, the compressive strength of foamed samples is lower. The amount of slurry decreases as the amount of foam used increases. This situation causes a decrease in dry density. There is a linear relationship between the dry density of the prepared foam concrete and its compressive strength. As the dry density increases, the compressive strength increases [Yang, D et al (2016)]. In addition, the porosity increases with the increase in the amount of foam. Increasing porosity causes an increase in the amount of air voids, thus decreasing the compressive strength. On the contrary, when the amount of foam is reduced, the amount of cement used increases, thus increasing the compressive strength [Bayraktar, O.Y et al 2021].

The type of foam used also affects the strength. Looking at the studies in the literature, protein-based foaming agents provide better compressive strength than synthetic ones. Falliano et al. [Jones, M et al 2005] reported that foam concrete containing a protein-based foaming agent, with a w/c of 0.5, showed higher compressive strengths, and a synthetic-based foaming agent, with a w/c of 0.3, led to higher compressive strengths. He observed that protein-based foaming agents increased the compressive strength of foam concrete.

The curing method applied to the samples affects the strength. Air, water and cellophane curing methods were used in the studies. It was observed that the air curing method resulted in the lowest strength values. The reason for this is the lack of optimal conditions for the hydration of the samples Falliano, D . In contrast, the strength of standard curing and moisture-proof cured samples increased with increasing curing age

The addition of fibers can help limit crack propagation, thereby helping to increase compressive strength. The use of basalt and PVA fibers increases the compressive strength. A 38% increase in compressive strength was achieved by using 1% of sugar cane pulp fiber. Compressive strength is adversely affected by increasing the amount of fiber. As workability decreases, the need for water increases, which negatively affects the strength [Madhwani, H et al].

Freeze Thaw Resistance

ASTM C666 determines the ability of normal weight concrete to resist rapid freezing and thawing cycles and produces microcracking and scaling type failure while conducting on foam concrete. Tikalsky et al. developed a modified freeze–thaw test procedure based on ASTM C666. Compressive strength, initial penetration depth, absorption rate variables have important effects on the production of freeze–thaw resistant foam concrete. It was reported that density and permeability are not important variables.

The water entering into the concrete expands during the freezing event and creates stresses. The porous structure of foam concrete provides good freeze–thaw resistance by providing additional space where water can expand [Bindiganavile, V et al (2008)]. Foam concretes generally offer good FT resistance compared to non-aerated concrete. Shon et al. [Shon, C.-S et al[] showed, as a result of their work, that foam concretes with high porosity did not always result in higher FT resistance. It was found that the FT resistance of foam concrete is affected more than the size of the air void, and the number of air voids smaller than 300 µm was reported to play a critical role in reducing FT damage in foam concrete. Since the number of freeze–thaw cycles increases, mass losses increase and spallings occur on the surface of foam concrete samples [Nambiar, E.K et al]. The type of foam used in foam concrete has an effect on mass loss and strength loss [Li, T et al (2020)]. Density difference affects the FT resistance of foam concretes. It was reported that low density foam concretes experience more expansion and high loss of mass and strength. This situation was attributed to the larger and interconnected pore structure of low-density foam concretes. Such a pore structure will allow more water intake into the concrete, causing the foam concrete to show lower resistance to FT She, W. et al.

Water absorption

Foam concretes designed for interiors, such as wall elements inside the building, are generally not exposed to water. In such cases, water absorption is not important, as foam concrete will not be affected by freezing–thawing. In this context, the water absorption is important as freeze–thaw effects posing a threat to foam concrete if it is used as an external element. Foam concretes used as external elements and structural elements are required to have low water absorption values [Koksal, F et al (2020)]. The water absorption property of concrete is directly related to the spaces and pores in it. The connection of the pores with each other can have an effect of increasing water absorption. However, the presence of capillary voids within the concrete directly increases water absorption [,Kolias, S et al (2005)]. Air voids from the foam do not contribute to water absorption [Kolias, S et al (2005]. Increasing the paste amount increases the number of capillary pores in the foam concrete content. This allows greater capillary forces to occur. The penetration of water into concrete is not only dependent on the connection of porosity and pores; the pore diameter and distribution of pores also affect water absorption. With the increase in the w/c ratio, the absorption increases [Koksal, F et al (2020)].

Ma and Bing reported that water absorption increased significantly with increased foam volume in soil-based foam concrete. This is because the more stable foam increases, the more interconnected pores are formed. They also reported that the use of silica fume reduced water absorption. The time required for water to penetrate the concrete is different from concrete without silica fume. In other words, soil-based foam concrete with silica fume may have more fine and unconnected pores.

The water absorption of the foam concrete increased by using the RCA as fine aggregate. The reason for this is due to the high water absorption feature of RCA. In other words, the water absorption properties of the aggregates used affect the water absorption of the foam concrete [Pasupathy, K et al (2021)].

In the study performed by Gopalakrishnan et al., FA and quarry dust were used. The quarry dust was used as a fine aggregate partially replaced by sand, and FA replaced cement. As a result of the study, it was seen that the best water absorption performance was achieved in the presence of 30% FA with quarry dust. It was reported that the water absorption was directly related to the density of the foam concrete [Gopalakrishnan, R et 2018].

Fibers added to foam concrete can increase water absorption. In connection with the water absorption properties of the fibers, there is an increase in water absorption. As it is known, natural fibers have water absorption properties. For example, in foam concrete where sugar cane pulp fibers are used, the rate of water absorption is increased for this reason [Gopalakrishnan, R et al].

Shrinkage Behaviour

Foamed concretes have the disadvantage of high drying shrinkage and are affected by foam volume, aggregate type, mineral additive, fiber content and water content. The cracking phenomenon is particularly related to the uneven volume change during the curing process due to the temperature difference caused by the heat of hydration under the thermally semi-adiabatic condition of the matrix [Kolias, S et al (2005)].

The shrinkage in foam concrete is a function of the foam volume. Therefore, it is related to the paste amount and paste properties. Nambiar et al. reported that although removing water from relatively larger artificial air pores does not improve shrinkage, artificial air voids may indirectly have some degree of effect on volume stability by enabling some shrinkage occurrence. This situation occurred more frequently at a higher foam volume [Nambiar, E.K.K et al (2009)].

Drying shrinkage increases with increasing density of foam concrete [Mastali, M et al (2018)]. Higher amount of foam with lower densities reduces the amount of cement. Thus, the hydration products are reduced, and less shrinkage occurs [Krishna, A.S et al (2021)]. The reason why the foam used has an effect on drying shrinkage may be the pore structure that occurs. It was reported that the pore size and pore attachment increased with increasing the amount of foam, thus decreasing the shrinkage [Nambiar, E.K.K et al (2009)]. A lower pore connection may help reduce drying shrinkage [Li, T et al (2020)].

An amount of shrinkage varying between 0.1% and 0.35% of the total amount of hardened foam concrete occurs. The main method used to prevent shrinkage is the use of fiber. The fiber-containing foam concrete resists shrinkage, resulting in less drying shrinkage. The increase in fiber content helps to increase the resistance to drying shrinkage and reduces the amount of shrinkage that occurs [Madhwani, H et al(2020)]. The type of fiber used may show different performance regarding shrinkage. Raj et al. reported the effects of PVA fiber and coir fiber on the drying shrinkage of foam concrete. The use of PVA fiber increases drying shrinkage. The reason for this was shown to be that early on, the PVA fiber retains water and shrinks, releasing the water as the concrete hardens. Reduced drying shrinkage was experienced with the use of coconut fiber. The fact that coconut fiber has water-retaining properties explains this situation. The use of sugar cane fiber also limits the changes in foam size, reducing soot shrinkage [Madhwani, H et al(2020)].

FA has negative effects on drying shrinkage. In the study where FA was used as fine aggregate, there was an increase in drying shrinkage with the use of FA. This is due to the greater presence of free water in FA pastes and therefore more evaporating water [Nambiar, E.K.K et al (2009)]. The use of clay brick powder from construction and demolition waste as additional cement material was reported to improve the drying shrinkage behaviour of foamed concrete [Gong, J et al (2019)]. Drying shrinkage of foamed concrete was reduced when silica sand was replaced with WMP. The reason for this may be the grain shape of the WMP and the pore size distribution of the foam concrete. As mentioned earlier, the pore structure affects drying shrinkage. The improvement in the pore structure reduces the drying shrinkage thanks to the decreased evaporation from the capillary pores [Bayraktar, O.Y et al].

Porosity

The strength and durability properties of cement-based materials are affected by the porosity, permeability, pore size and distribution of the material [Jones, M.R et al (2005)]. If we consider the pore structure of foam concrete in general, it has three types of porosity: gel pores, capillary pores and air pores [Nguyen, T.T et al (2007)]. While capillary and air pores affect the strength properties of foam concrete, gel pores have no effect on the strength [Jones, M.R et al (2005)]. The pore distribution and size of the foam concrete directly affect its mechanical and physical properties. Therefore, the properties of the porous structure are very important for foamed concrete [Krishna, A.S et al (2007)].

Then compared to synthetic-based foaming agents, protein-based foaming agents create smaller and homogeneous air spaces at high foam concrete densities [Panesar, D. et al (2016)]. In the study conducted using synthetic, plant and animal glue/blood-based surfactant, the pore walls of foam concrete containing SS were thicker and less connected than others. The smaller pore size of the SS-containing foam concrete and its low pore connection enabled the foam concrete to gain features such as high compressive strength, low water absorption and stronger frost resistance [Li, T et al (2020)].

The air voids in the hardened concrete have two different effects on the concrete. On the one hand, the strength decreases with the increase in air content in concrete. Additionally, in hardened concrete, a well-designed air system can improve freezing–thawing resistance[. Providing an optimal air void system in foamed concrete is very important to produce a material with a high strength/weight ratio

The narrowness of the air voids contributes to the increase in strength. With the increase in the amount of foam, mixtures with narrower air void size distribution show higher strength Increasing the foam dosage increases porosity . Hashim and Tantray's study compared the performance of protein and synthetic foaming agents. As a result of the study, it was reported that the size of the air voids increased with the decrease in the density of the foam concrete for both types of foam. The reason for this can be shown as the amount of foam increases, there is an increase in the amount of air voids, and therefore the overlapping of the air voids can be combined. The combined air spaces create a wide distribution of pores, which results in lower strength

In the use of glass and plastic wastes as filling material, glass wastes provide more uniform distribution of voids and a less interconnected void structure. This is attributed to the finer glass waste powder. It was reported that thinner fill materials create uniform air pockets [Chandni, T et al (2018)]. The use of fly ash as a filler provides a more homogeneous distribution of air voids compared to fine sand. It provides a good and homogeneous coating on the bubble, preventing bubbles from overlapping and coalescing, thus helping to distribute the air voids evenly [Jones, M.R. et al (2008)]. Nambiar and Ramamurthy reported that FA [Jones, M.R. et al (2008)], when used in foam concrete, provides a good homogeneous coating on each bubble, and that these coatings help the uniform distribution of air voids and prevent blisters from coalescing. These properties lead to higher strengths.

The increase in the amount of water provides the enlargement of the air voids [Jiang, J et al (2016)]. Growing pores have less void surface area. In addition, the increase in the amount of water increases the number of capillary pores. In fact, for the same porosity, the increased fraction of capillary pores leads to a decreased number of air pockets. The pore size is reduced by the use of SA. Increased amounts of SA also result in increased ability of the slurry to contain air bubbles and as a consequence, the size of the pores is decreased [Jiang, J et al (2016)]. The use of superplasticizer helps in improving the void structure . With the increase in superplasticizer content, it provides lower water consumption, thus, a better pore structure, thicker porous wall and a stronger matrix are formed. In this way, foam concrete demonstrates higher strength [Jiang, J. et al (2021)].

Porosity is accepted as a main parameter that directly affects the physico-mechanical, thermal and durability properties of foam concrete [Gencel, O et al (2021)]. The type of aggregate used affects the porosity. The pore structure of the aggregate type used affects the porosity of the foam concrete [[Gencel, O et al (2021), Oren, O.H et al (2020)]. The use of RCA as fine aggregate was investigated in the study of Gencel et al. As a result of the study, an increase in apparent porosity occurred with the use of RCA. This situation was attributed to more porous texture forms than natural sand.

By using the RCA as a fine aggregate in geopolymer foam concrete, a more homogeneous pore distribution was achieved. In addition, thinner air pockets occurred in RCA-containing foam concretes. This can be attributed to the greater stability of the samples containing RCA. In stable mixtures, thinner and homogeneous distribution of air voids occurs [Pasupathy, K et al (2021)]. In the use of glass and plastic wastes as filling material, glass wastes provide more uniform distribution of voids and a less interconnected void structure. This was attributed to the finer glass waste powder. It was reported that thinner filling materials create uniform air pockets [Chandni, T et al (2018)]. The use of waste marble dust and RHA in foam concrete reduces porosity. Materials with pozzolanic properties improve the interfacial transition zone, thanks to the filling effect. Thus, it was reported that it provides a filling effect that reduces porosity by providing effective particle packaging [Gencel, O et al (2021)].

3.2. Materials

- Cement: Ordinary Portland Cement (OPC) will be used according to [specify standard].

- Fine Aggregate: Natural sand will be used as the fine aggregate, meeting [specify standard] for particle size and cleanliness.
- Coarse Aggregate: Stone dust will be used as a partial or full replacement for traditional coarse aggregate. The stone dust will be characterized by its particle size distribution and specific gravity, ensuring it conforms to the standards of a suitable coarse aggregate.
- Foaming Agent: Hydrogen peroxide (H_2O_2) will be used as the foaming agent. Different concentrations of H_2O_2 (3%, 6%, and 9% by volume) will be used to prepare the foam. The foaming process will be initiated by mixing H_2O_2 with an alkaline solution (e.g., sodium hydroxide, NaOH) that decomposes the H_2O_2 to produce oxygen bubbles, creating foam.
- Water: Potable water will be used for the mixing process.
- Admixtures: Any chemical admixtures (e.g., plasticizers or retarders) will be added according to the requirements of the mix design to ensure workable consistency.

3.3. Preparation of Foam Concrete Mixes

1. Mix Design: The concrete will be designed with a constant water-cement ratio (e.g., 0.45) and varying amounts of stone dust as coarse aggregate (e.g., 25%, 50%, and 75% replacement by weight). The amount of H_2O_2 will also be varied (3%, 6%, and 9%) to understand its influence on the properties of foam concrete.
2. Foam Generation: Foam will be produced by mixing H_2O_2 with NaOH in water to generate oxygen bubbles. The foam is then incorporated into the concrete mix to form the hybrid foam concrete. The amount of foam generated will be controlled to maintain the desired density and workability of the foam concrete.
3. Mixing: Cement, fine aggregates, stone dust (as coarse aggregate), and water will be mixed thoroughly in a concrete mixer. The foam will then be incorporated into the mixture carefully to ensure uniform distribution without breaking the bubbles.
4. Casting: The prepared foam concrete mix will be poured into standard molds (e.g., 150mm × 150 mm × 150 mm cubes for compressive strength, 150 mm × 300 mm cylinders for other tests) and compacted to eliminate air voids. The specimens will be left to set at room temperature for 24 hours before curing.

3.4. Curing Conditions

Three distinct curing conditions will be used to assess their effects on the durability of hybrid foam concrete with H_2O_2 and stone dust:

- Water Curing: Concrete specimens will be submerged in water at room temperature (approximately 23°C) for 7, 14, 28 days to evaluate the long-term effects of water curing.
- Air Curing: Concrete specimens will be air-cured in a controlled environment with a relative humidity of 70% and a temperature of 23°C for 7, 14, 28 days to simulate real-world curing conditions.
- Steam Curing: Some specimens will undergo steam curing at 60°C for 6 hours per day to simulate accelerated curing conditions. The samples will be subjected to [X] number of cycles for comparison.

3.5. Testing and Data Collection

After curing, the following tests will be performed on the concrete samples to assess durability and mechanical properties:

1. Compressive Strength Test: The compressive strength of the foam concrete specimens will be tested according to ASTM C39 at 7, 14, 28days to evaluate the impact of H_2O_2 and stone dust on concrete strength under different curing conditions.
2. Water Absorption Test: Water absorption will be determined by submerging the specimens in water for 24 hours and calculating the percentage increase in mass, following ASTM C642. This test will provide insight into the material's porosity and permeability.
3. Porosity Test: The porosity of foam concrete will be evaluated by the water displacement method (Archimedes principle), determining the volume of voids in the material. This will help assess how the foaming agent (H_2O_2) and stone dust influence the microstructure of the concrete.
4. Freeze-Thaw Resistance Test: Samples will undergo freeze-thaw cycles according to ASTM C666 to assess their resistance to temperature extremes. After a specified number of cycles (e.g., 50 cycles), the samples will be tested for residual compressive strength and water absorption to determine freeze-thaw durability.
5. Shrinkage Test: Drying shrinkage of the concrete will be measured using ASTM C157 standards. Shrinkage strain will be recorded at various time intervals (7, 14, 28 days).

3.6. Statistical Analysis

- Descriptive Statistics: Descriptive statistics (mean, standard deviation) will be used to summarize the results of compressive strength, water absorption, porosity, and other tests.
- Regression Analysis: Multiple regression models may be used to predict durability properties (e.g., compressive strength, porosity) based on the amount of H_2O_2 and stone dust used in the mix.

3.7. Control Variables

- Mix Consistency: All concrete mixtures will be prepared with consistent water-cement ratios and stone dust percentages. The foam will be generated using consistent H_2O_2 concentrations to ensure reproducibility.
- Environmental Factors: All curing tests will be conducted in a controlled laboratory environment with temperatures between 20°C and 25°C and relative humidity maintained between 50% and 60%.

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