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A STUDY OF PERFORMANCE OF CONCRETE IN RELATED TO CONCRETE WORKABILITY, DUCTILITY AND COMPRESSIVE STRENGTH

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ABSTRACT

To counteract HPC's limited workability caused by its low water content, admixtures of either mineral or chemical are often added to the slurry. In order to provide the appropriate workability, pozzolanic mineral admixtures including fly ash, rice husk ash, and met kaolin are frequently utilized. Alccofine 1203 (AF), Met kaolin (MK), and Ground Granulated blast furnace slag (GGBS), as well as Strongcrete (SC), Nokrack (NK), and Flat crimped steel (FCS), are the three types of mineral admixtures and fibers used in this study, respectively. High-performance concrete's mechanical and durability qualities were examined after varying amounts of fibers were added to the mix. The initial warped curing period lasted 24 hours, and further water curing was followed by the measurements. Concrete's mechanical qualities were evaluated using tests for compressive strength, split tensile strength, flexural strength, and durability including water absorption, seawater test, sulfate attack test, sorptivity, and water permeability. Moreover, Scanning Electron Microscopy (SEM) and X-Ray Diffraction were used to examine the microstructural and chemical make-up of the optimal blend (XRD). High-performance concretes benefited from mineral admixtures and fibers, but to varying degrees, depending on the binder and fiber used.

KEYWORDS: Concrete Workability, Compressive Strength, pozzolanic mineral admixtures, Concrete's mechanical qualities, Scanning Electron Microscopy, High-performance concretes

INTRODUCTION

Concrete's tensile strength and strain capacity at fracture are both rather weak. Pretensioned steel or reinforcing bars have long been used to remedy these deficiencies. The placement and continuity of the reinforcing steel were carefully considered to provide optimal performance. Concrete's fibers are intermittent and often scattered throughout the material. One may find examples of the usage of fibers in structural applications with traditional reinforcement in Fiber reinforced concrete, due to its adaptability in manufacturing processes, may be an inexpensive and beneficial building material (for further information, Slabs on grade, mining, tunneling, and excavation support applications are only some of the places where steel and synthetic fiber reinforced concrete and shotcrete have been employed (for further examples,)

Constituents of fiber reinforced concrete

The components of fiber reinforced concrete include cement, aggregates, water, admixtures, and fibers.

Cement: Standardized by the American Society for Testing and Materials as type-I cement, Ordinary Portland Cement (OPC) is the cement of choice (ASTM).

Aggregates: Similarly to regular concrete, fiber reinforced concrete may be made using any aggregates that work for regular concrete. Fine and coarse aggregates are the two standard classifications. Sand, natural, crushed, or man-made, is a common fine aggregate. Aggregates with a coarser particle size might be of a typical, low, or high density. Natural gravel or crushed stone can be used to make standard-weight coarse aggregates. Expanded clay (like shale or pumice) or blast furnace slag are commonly used to create lightweight coarse aggregates

Water: Fiber reinforced concrete is more effective when used with potable water. Cement hydration and shaping concrete require the presence of water. The amount of water needed for hydration is around 0.28, as shown

Admixtures: Admixtures may be broken down into three broad categories: those that reduce the amount of water used, those that add minerals, and those that add other chemicals. Fibers tend to decrease the workability of a cement matrix. Using water-reducing admixtures, fiber-reinforced concrete may still be worked without the use of extra water. Strength decreases, shrinkage rises, and cracking increases due to the additional water, hence durability suffers. With the addition of super plasticizers, the flowability of the mixture is not compromised even at a w/c ratio of 0.28. Mineral admixtures include things like fly ash, silica fume, and so on. The workability and heat of hydration can both be lowered by using fly ash. High-strength, fiber-reinforced concrete is often achieved with the addition of silica fume. Including these admixtures into the matrix results in a denser matrix, which improves the composite's mechanical characteristicsThe bond strength and durability of concrete are both enhanced by the presence of silica fume Fiber reinforced concrete has been utilized with air entraining, speed-up, and slow-down admixtures. Nonetheless, air entrainment is the most prevalent admixture for outside constructions.

Fibers: Steel, glass, synthetic and natural fibers make up the four main classes of fibers. Several sized and shaped fibers may now be manufactured. The aspect ratio of a fiber is easily calculated by dividing its actual length by its comparable diameter. Lengths between 10 mm and 75 mm often fall within the 30–150 aspect ratio range.

Steel Fibers: Fibers consisting of steel (either carbon steel or stainless steel) are sometimes referred to as metallic Fibers. Tensile strength can be anything from 345 MP and 1380 MP [26]. ASTM requires a minimum strength of 345 MP. Around 200 GA is the elastic modulus for metallic fibers. The form of the fiber's cross section might be anything from a circle to a square to a crescent to an irregular shape. Steel Fibers are divided into three distinct types by the Japanese Society of Civil Engineers (JSCE) depending on the shape of their cross section: Type 1 is a square section, Type 2 is a circular section, and Type 3 is a crescent section. Steel Fibers are categorized by ASTM a 820 into four broad categories, depending on the raw material they are made from. Cold-drawn wire (Type I), cut sheet (Type II), melt-extracted fiber (Type III), and other fibers (Type IV).

Polymeric Fibers: Textile and petrochemical factories have manufactured synthetic polymeric fibers. Fibers such as acrylic, aramid, nylon, polyester, polyethylene, polypropylene, etc., are included here. The modulus of elasticity of the majority of these fibers is low (except for aramids). The aspect ratios of these Polymeric Fibers are quite high. Single filament and fibrillated forms of polymeric fibers are commercially available.

Carbon Fibers:is often manufactured in tows (strands) that can have up to 12,000 individual filaments. Before being mixed into cement matrices, these stands are often spaced out. The strong tensile and flexural strength of carbon fibers has led to their widespread application. Carbon fibers are twice as strong as steel and have elastic moduli comparable to steel's. With a specific gravity of only approximately 1 percent, they are very lightweight. When exposed to most substances, they don't react .

Glass Fibers:GFRC Sheets, which are made of cement and glass fiber, are the most common use. It was discovered that regular E-glass fibers degrade in concrete. The discovery that alkali may dissolve glass led to the creation of AR-glass fibers. Mostly, GFRC is used for architectural panels.

Naturally occurring Fibers:are the earliest examples of composites made using fibersThey include akwara, bamboo, coconut, flax, jute, sisal, sugarcane bagasse, straw, chip, horse tail, goat hair, plume, wood (cellulose), Brucite, and San.

Mechanical properties of fiber reinforced concrete

Mechanical characteristics of FRC are affected by its volume, fiber length, fiber type, fiber orientation, fiber diameter, and fiber aspect ratio. Normal concrete and fiber reinforced concrete have similar first and last setting times. When fiber is added, the droop and the amount of air within decrease. Somewhat more air is lost from fiber reinforced concrete during the slumping process (see Ref. Fiber addition significantly decreased the workability of the concrete, and it was discovered that the highest fiber content concretes were the most challenging to work with. Because fibers of varying shapes and lengths can exert greater control over the micromechanics of crack formation at varying strain levels than single-type fibers, mixtures made with combinations of different steel fibers achieve higher first-crack loads in bending than those made with only one type of steel fiber.

The initial fracture load of a micro-macro fiber combination is often higher than that of a combination of macro Fibers. As a result of their smaller critical inter fiber space, micro Fibers are better able to regulate the coalescence of micro fractures, which is the most plausible explanation. Steel fibers improve the strength-to-weight ratio.

Because the inertia force created in a structure due to group shaking depends upon its mass, this improvement in strength to weight ratio is very important for the construction of earthquake-resistant buildings. In addition, the average residual strength improves as the fiber content rises.

Fibers with an aspect ratio larger than 100 often exhibit the phenomena of "curling up" of Fibers, which is caused by the Fibers' inherent lack of stiffness (see Ref.

Compressive strength

Researchers Nehdi et al., who worked with fiber reinforced self-consolidating concrete (FRSCC), found that some steel fiber combinations appeared to boost the compressive strength of FRSCC beyond what could be obtained with single type steel Fibers.

While the use of synthetic macrofibers has been shown to reduce compressive strength, the use of hybrid blends containing both synthetic and steel fibers has been shown to mitigate this effect, most likely as a result of the higher stiffness of the steel fibers and better control of micro-macro cracking.

To learn more about how polypropylene structural fiber affects the performance of concrete, Nutter et al. conducted an experimental study.

They found that when fiber reinforced concretes were exposed to compression or bending, the mode of failure changed from brittle to ductile.

As the percentage of fibers in the material grew, so did the average residual strength.

Flexural strength

Flexural strength testing of fiber reinforced concrete is the subject of ACI Committee 544.2R Steel fibers have a far larger effect on the flexural strength of concrete than they do on the direct tension and compression strengths, as was documented by the ACI Committee 544.4R. For flexural strength, two numbers are often reported: the first-crack flexural strength, which is the load at which the load-deformation curve no longer exhibits linearity, and the second, the ultimate flexural strength. The ultimate flexural strength, often known as the modulus of rupture, is equal to the value represented by the other.

Singly reinforced rectangular concrete beams with and without steel Fibers and longitudinal steel bars have been analyzed for their flexural strength using a revised and semi-empirical analytical approach established by Kumar. Researchers Ganesan et al. looked at how adding steel Fibers to self-compacting concrete (SCC) flexural components affected their strength and behavior, and they discovered that both the initial crack load and the post-cracking behavior were much enhanced by the Fibers. Concrete's flexural strength and ductility can be improved by using steel fibers recovered from old tires, as indicated by the research conducted by Neocleous et al.

According to the flexural study conducted by Gopalkrishan et al., steel Fibers are added to shotcrete to boost its ductility, energy absorption, and toughness. This is the job that steel fibers in shotcretefulfill, and they do it by preventing the material from breaking too much and keeping it together when a lot of cracking has already happened. The results of static testing on steel fiber reinforced shotcrete panels demonstrate clearly the gains in energy absorption capability with increasing percentage of steel Fibers. The research also shows that traditional shotcrete may be performed with Fibers having aspect ratio 75 to 100 for which shotcrete machines should have adequate nozzle size for straight steel Fibers of 25mm length with aspect ratio of 61.5 for usage in field applications.

Shear strength

Using standard and high-strength steel fiber reinforced concrete specimens, Barragan et al. conducted direct shear push-off tests for their experimental investigation. When compared to regular concrete, steel fiber reinforced concrete (SFRC) fails in a very different way. The addition of steel fibers to both regular and high-strength concrete significantly increases the ductility of the material during shear failure and also boosts its shear strength.

The shear behavior of fiber reinforced concrete with flattened ends, circular cross section, and crimped geometry and crescent cross section type Fibers has been studied by Mirsayah et al. Both fibers were shown to significantly increase shear strength and shear toughness, with the benefits increasing with increasing fiber dose. Both the crimped fiber and the one with flattened ends were found to be effective. Experimental work by Kahn et al. has been expanded to high-strength concrete, and the authors indicate higher shear friction strengths for pre-cracked, cold-joint, and un-cracked specimens. In addition, it is suggested that the maximum allowable shear stress not be less than 20% of the concrete strength. To analyze and experimentally investigate the shear transfer behavior of reinforced concrete over a fracture, Mansur etal.used pre-cracked push-off specimens.

Steel Fibers of varying shapes, sizes, and volume concentrations were used to replace the vertical stirrups in a conventional reinforced beam loaded in flexure by Batson and Jenkins . They found that steel Fibers outperformed the vertical stirrups and the bent-up flexural stirrups in a number of respects. Fibers are first dispersed uniformly throughout the concrete's volume at denser intervals than even the tiniest reinforcing rods can achieve. Second, the steel fibers improved both the initial and final tensile strengths.

Crimped steel 50 mm in length was used in the experiments by Swamy and Bahia. Shear deformation was observed to be minimized across all loading stages when steel fibers were present; this effect became more pronounced with increasing fiber concentration. The fibers in the beam prevented any breaking or displacement from occurring in the dowel zone, allowing the dowel action to completely develop. The shear strength of a beam with a shear deficiency was enhanced by the addition of fibers, and the beam was able to attain its full flexural capacity in ductile flexural failures.

Toughness

Toughness is the capacity of a composite to absorb energy, and it is measured as a ratio of the energy needed to deflect the beam to a given deflection, in multiples of the energy released at the first crack in the beam. Fiber reinforced concrete is known for its durability. It's a key mechanical performance metric that needs to be guaranteed when designing for niche uses like earthquake and impact resistance or tunnel linings. According to the research presented by

Taylor [66], increasing the fiber volume fraction of SFRC from 2% to 3.75 % led to a toughness index that was around 100% greater than that of standard SFRC. Hooked steel fibers are the toughest of all the other types of steel fibers tested, including straight, deformed, and corrugated fibers.

Modulus of elasticity

Fiber reinforced concrete's modulus of elasticity is 30%-80% more than that of ordinary concrete There is a direct relationship between the aggregate's volume and modulus and the concrete's modulus of elasticity. Including some steel fibers in the mix probably won't make much of a difference to the composites' modulus. Lightweight concrete aggregates' young's modulus has been shown to be affected by both steel fiber reinforcement and polymer modification, as investigated by Kurugol et al. Results from this investigation show that, in steel fiber reinforced lightweight concrete mixes, the young's modulus of elasticity drops when the volume percent of coarse aggregate is replaced with lightweight aggregate. Rapidity of decline is highly proportional to the volume fraction of the whole. The polymer has a beneficial influence on the modulus of elasticity at low polymer volume ratios.

According to Bhikshma and Singh , the modulus of elasticity of M30 grade concrete was found to rise by 16%, 41%, and 50%, respectively, when steel fibers were added at concentrations of 0.25, 0.5, and 1.0 percent. As with M30 grade concrete, the inclusion of steel Fibers increased the strength of M35 concrete by 25%, 43%, and 55% above the strength of unreinforced concrete. With 1.0% steel fibers added to recycle aggregate concrete, the modulus of elasticity increases by 50% compared to that of plain concrete.

STEEL FIBER REINFORCED CONCRETE

In most cases, steel fibers are employed as an adjunct to reinforcing bars in structural applications. Resistance to fatigue, impact, shrinkage, and thermal stresses may be increased, and cracking can be prevented, with the help of steel fibers. The need for more fundamental knowledge on the behavior of concrete and fiber reinforced concrete under different types of loads is of crucial relevance as the performance requirements of structural applications continue to rise. Different factors, such as the type of fiber used, the length-to-diameter ratio (aspect ratio), the amount of fiber, the strength of the matrix, the size, shape, and method of preparation of the specimen, and the size of the aggregate, can affect the mechanical properties of steel fiber reinforced concrete (SFRC) see Ref.[40]. All modes of failure, including direct tension, bending, impact, and shear, are affected by the addition of fiber to concrete and mortar, although fatigue and tensile stress are most exacerbated. The strengthening mechanism of the Fibers included transfer of stress from the matrix to the fiber via interfacial shear or by interlock between the fiber and matrix if the fiber surface is bent. When under tension, the fibers and matrix work together to distribute the force, but as the matrix begins to break, the whole force is transmitted to the fibers. The effectiveness of the fibers used and the amount of fibers used are two of the most influential factors in determining how fiber reinforced concrete performs, even more so than the matrix itself (Percentage of fiber by volume or weight and total number of Fibers). Fiber efficiency is governed by the resistance of the Fibers to pullout, which in turn depends on the bond strength at the fiber-matrix interface. For Fibers with uniform section, pullout resistance increases with an increase in fiber length, the longer the fiber the greater its influence in enhancing the qualities of the composite.

Also, due to the fact that pullout resistance is related to interfacial surface area, non-circular fiber cross-sections and smaller diameter round fibers require greater pull out resistance per unit volume than larger diameter round fiber. A larger interfacial area (or a smaller diameter) results in stronger adhesion between the Fibers. Consequently, for a given fiber length, a high ratio of length to diameter (aspect ratio) is associated with high fiber efficiency. To ensure that the Fibers' tensile strength is approached when the composite fails, it seems they should have a sufficiently high aspect ratio. Sadly, this is impractical. Several studies have demonstrated that when fibers with an aspect ratio of more than 100 are used in concrete, the mixture either becomes too stiff to work with or the fibers are distributed unevenly throughout the concrete. Most commonly used composites have fibers with aspect ratios of less than 100, meaning that fiberpullout is the primary cause of failure. Fibers with curved surfaces or end anchoring, on the other hand, improve resistance to draw out without altering aspect ratio. Even if part of the Fibers are broken when the failure occurs, pull out is typically the governing factor.

When compared to a sudden and potentially catastrophic failure that may occur if the Fibersbreak in tension, the pullout form of failure has the benefit of being slow and ductile. More often than not, ductile steel is the better option. The more fibers there are in the mix, the more resilient and slow the concrete will crack. Steel fiber reinforced concrete's mechanical qualities vary depending on the kind and number of fibersused, therefore knowing this information is crucial for good design [70]. In comparison to plain concrete and even the traditionally reinforced concrete used in civil and defense engineering, steel fiber reinforced concrete (SFRC) is proposed by Wang et al. to have many excellent dynamic performances, including high resistance to explosion and penetration, in addition to various mechanical properties.

POLYMER MODIFIED FIBER REINFORCED CONCRETE

Since polymer dispersions entrain so much air in concrete, they make the material easier to work with yet weaken it overall. As a result, the proportion of water to cement in polymer-modified concrete must be altered. Polymer-induced water content reduction and defoaming agents, as proposed by Mangat, can further reduce entrained air, he said. In order to increase specific physical and mechanical qualities while maintaining its strength, cheap cost, and capacity to fill practically any form, modern cement matrix material research is focused on the introduction of additives, admixtures, and short Fibers. Cement matrix materials have been studied in a variety of ways, with a focus on their adhesion, permeability, thermal and acoustic insulation, ductility, flexural strength, fire performance, and viscous damping.

Cement-based materials that benefit from the addition of polymeric admixtures are those in which the polymer serves as a primary element in the modification or improvement of the material's qualities. Polymer latex, polymer powder, polymer liquid, and polymer that dissolves in water are all examples of suitable polymeric compounds. Among all the forms that polymer admixtures might take, polymer latex has found the most widespread application. Polymer modified mortar was shown to have a significant impact on the mechanical characteristics of concrete composites, as investigated by Barluenga and Hernan It is the mechanisms of cement hydration and polymer film production in the binder phase of cement mortar/concrete that dictate the alteration of these materials with polymer latex. The result of both procedures is a co-matrix. When applied to a cementitious medium, polymer dispersions take the form of a collection of plastic microspheres suspended in water. Because the diameter of these spheres can be on the order of 0.1 mm, a stabilizing mechanism must be included in the water suspension to prevent the polymer particles from clumping together.

According to research conducted by Neelagmegam polymer modification using SBR latex and the appropriate mix of wet-dry curing significantly increases the flexural strength of concrete. While the early wet curing stage aids in cement matrix strength development, the subsequent dry curing time aids in SBR film production and enhances adhesion between the cement matrix and concrete particles. According to Bing and Liu combining wet and dry curing greatly improves outcomes. If you're using polymer-modified concrete, this curing method could be your best bet. Possible explanations for this include the fact that SBR latex solidifies better in a dry curing environment and that water curing during the early curing stage promotes full hydration of the cement matrix. As a result, cement matrix adhesion and SBR film strength are both improved. Hence, it can be concluded that the strength development of polymer modified concrete is best achieved by a mix of wet curing and dry curing.

Shear Capacity of Fiber-Reinforced Polymer- Strengthened Reinforced Concrete Beams was investigated by Chen and Teng. This study's main contribution is the recognition that, due to the non-uniform strain distribution in the FRP and the linear elastic brittle behavior of FRP, the stress distribution in the FRP along the shear crack is non-uniform at shear rupture failure, and the explicit account taken of this stress non-uniformity in the new strength model.

Polymer modified steel fiber- reinforced concretes (PSC) were the subject of research by GengyingLi for use as highway coverings or in subterranean structures. The ductile behavior and flexural strength of steel fiber-reinforced cement concretes are enhanced by the addition of a styrene butadiene rubber emulsion (SBR) (SFC). Cement matrices can also be made denser with the use of silica fume and fly ash. Since steel Fibers and SBR are so expensive individually, we'll be looking at the best ways to combine them to create composites with desirable mechanical qualities at a reasonable price.

The Impact Behavior of SBR-Latex Modified Fiber Reinforced Concrete Beams was investigated by Khan etal.Using experimental programs, this investigation focuses on the impact and post-impact residual strength of an SBR (Styrene Butadiene Rubber) latex modified steel fiber reinforced high strength concrete beam subjected to repetitive low-energy horizontal impact loads. Static and impact loads were shown to be related by DRI. As impact loading was increased, a decrease in the dynamic response index (DRI), an indirect measure of stiffness and strength of the test specimens, was seen. The addition of fiber and latex to the concrete matrix increases the toughness and fracture capacity, hence improving the dynamic behavior and residual strength of structural parts.

HIGH PERFORMANCE CONCRETE

In comparison to regular concrete, high performance concrete has increased durability and strength. High performance concrete may be defined as any concrete that meets a set of requirements designed to overcome the shortcomings of regular concrete. High-performance concrete (HPC) represents the state of the art in this material. These days, you may see it employed in all sorts of high-profile construction, from flyovers to multistory structures to bridges. Building with HPC has become common practice since the 1990s. The adoption of HPC has just become global. "A concrete which fulfills unique performance and homogeneity standards that cannot always be reached using only the normal ingredients and mixing, putting, and curing techniques," reads a definition provided by the American Concrete Institute (ACI) in 1993. HPC is specified by the Strategic Highway Research Programmed (SHRP) for highway use based on the following requirements for strength, durability, and w/c ratio.

- It should satisfy one of the following strength criteria:
- 4 hour strength ≥17.5 MPa
- 24 hour strength ≥35.0 MPa
- 28 days strength ≥ 70.0 MPa
- It should have a durability factor greater than 80% after 300 cycles of freezing and thawing.
- It should have a water-cement ratio of 0.35 or less.

With the rise of the concrete industry came the need to find ways to save costs without sacrificing quality, hence the use of mineral admixtures has skyrocketed in recent years. Yet, efforts to minimize cement use through the use of supplemental cementitious materials have arisen due to environmental concerns about the harm caused by the extraction of raw material and the carbon dioxide emission during cement manufacturing. More often than not, mineral admixtures are employed in the creation of HPC mixes. They include fly ash, rice husk ash, met kaolin, silica fume, etc. The combination of increased performance and reduced costs is made easier with their assistance. By decreasing the HPC's permeability, these materials improve its performance over time. There has been a noticeable uptick in HPC's strength and durability after the use of such materials. Nowadays in the concrete industry, high reactive met kaolin is useful for boosting compressive strength and decreasing sulphate attack.

CONCLUSION

Every hybrid has come into existence for a unique reason and developed independently from the others. Certain admixtures have been combined to make their incorporation into the batching process easier, while others include chemistry that influences more than one property of the concrete.The effects of incorporating three different mineral admixtures, Alccofine 1203 (AF), Metakaolin (MK), and Ground Granulated blast furnace slag (GGBS), and three different fibres, Strongcrete (SC), Nokrack (NK), and Flat Crimped Steel Fibres (FCSF), into high-performance concrete at varying percentages on its mechanical and durability properties have been studied. A set of measurements were obtained after the initial 24 hours of distorted curing, and then the material was subjected to a period of water curing. Concrete's mechanical properties were evaluated using a battery of tests, including compression, split tensile, flexural, water absorption, seawater, sulphate attack, sorption, and permeability.It has been demonstrated that incorporating supplementary cementitious components in concrete may increase the material's performance while also benefiting the environment. Reduced landfill waste from the steel and clay industries and the carbon dioxide emissions from the extensive use of Portland cement in the concrete manufacturing industry are made possible by the use of green materials such as met kaolin, ground granulated blast furnace slag, and Alccofine 1203. Cementations elements were added to high-performance concrete (HPC) in this study to improve its properties. Experiments include testing and designing a mix for M80 grade materials that feature three different mineral admixtures (Metakaolin, Alccofine 1203, and GGBS) and fibres (containing flat crimped steel fibres and two different types of polypropylene fibres). The strength and durability characteristics of each combination were compared. In order to test the strength and endurance of the material, three specimens were cast at each curing period. The three most basic tests for the mechanical qualities of concrete—compressive strength, modulus of rupture, and split tensile strength—were included in the experimental programme. The mechanical properties of phase I concrete were assessed at 7 and 28 days, whereas those of phase II concrete were assessed at 7, 28, 59, 90, and 365 days. Cubes of concrete were evaluated for compressive strength after curing in water for 7, 14, 28, 56, 90, and 365 days. Concrete cylinders, 150 mm in diameter and 300 mm in height, were cured in water and then split to evaluate tensile strength. Water absorption, sorptivity, chloride assault, sea water attack, and permeability testing were among the extra durability tests performed on the concrete. The inquiry entailed testing both newly poured and aged concrete. Scanning electron microscopy and X-ray powder diffraction were also employed to further investigate the material's chemical make-up and microstructure.

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