

# ADVANCES IN PRODUCTION AND PERFORMANCE OF FUNCTIONALLY GRADED CONCRETE BEAMS: A REVIEW

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## Abstract

Functionally graded concrete is becoming increasingly popular due to the need to minimize global carbon emissions and advancements in automation. Functionally graded concrete varies material composition to fulfill different performance objectives across a structural part. This has tremendous possibilities for reducing cement usage. This paper explores recent advancements in the production and performance of functionally graded concrete (FGC) beams. Advanced production techniques like 3D printing and gradient casting allow for precise control over material composition, leading to complex, high-consistency structures. This reduces material usage, especially in high-demand regions, and contributes to lower carbon emissions. FGC's mechanical properties show improvements in tensile and compressive strength, crack resistance, and thermal resistance, making them suitable for energy-efficient designs. Computational modeling plays a crucial role in optimizing design for maximum structural efficiency. FGC beams show significant improvements in mechanical properties, including enhanced strength, better fracture resistance, and superior thermal performance compared to conventional homogeneous concrete. The performance of compressive strength in functionally-graded Preplaced Aggregate Fibrous Concrete (FPAFC) has been reported to reach 57 MPa, while its impact ductility index is 11.8%, demonstrating robust balance between strength and toughness. Moreover, an ultra-high-performance concrete (UHPC) layer integrated with headed studs has shown an impressive modulus of elasticity of 42.1 GPa, significantly enhancing the fatigue properties of the overall structure. The cracking behavior in asphalt concrete using a cohesive zone model (CZM), revealing a crack propagation threshold at 3.5 mm. Thus, the advancements in the production and performance of functionally graded concrete demonstrate its potential to deliver superior strength, durability, and sustainability in construction.

**Keywords:** Continuously Graded Concrete; Layered Concrete; Functionally Graded Concrete; Flexural Behavior; Impact Behavior; Compressive Strength

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## Introduction

Concrete is the most popular building material. The primary component of concrete, cement, account (Naik, 2020). Traditional concrete casting methods require a single, uniform mix of approximately 5% carbon dioxide emissions from human activities globally. Current construction rules and production techniques are a reflection of the widespread usage of concrete as a uniform material (Mohajerani *et al.*, 2019). In order to satisfy specifications like strength, durability, and deformability, an appropriate combination of material qualities is given. Next, a suitable composition for the concrete mix is chosen. As a result, a homogenous member's material qualities are often underutilized in most situations (Moradpour *et al.*, 2019). A low water to cement ratio is chosen for durability, but its low permeability is only utilized in peripheral regions where water and gas diffusion threatens its durability (Unnithan *et al.*, 2021).

Functional grading can consequently maximize the usage of concrete (Du Plessis *et al.*, 2021). To adapt the material qualities to regional requirements, the mix composition of functionally graded materials is changed throughout an element's shape. This enables the reasonable use of a particular material composition that satisfies numerous criteria only when it substantially enhances one or more of the element's functions (Phani and Oliver, 2019). Two main ways that functional gradation of concrete allows for cement reduction are to use high cement content if essential for performance measures like durability or strength, or to use lightweight mixes when regular weight mixes are not required. This reduces dead loads, makes it possible to design more slender structural elements with less material, and lowers the overall weight of concrete structures (Kromoser *et al.*, 2019).

Traditional concrete is a costly and environmentally damaging material due to its high carbon dioxide emissions and susceptibility to cracking, corrosion, and wear (Qureshi *et al.*, 2022). Its structural inefficiency and heavy weight can lead to over-engineering and underperformance in certain areas. Additionally, traditional concrete does not efficiently address thermal insulation needs, requiring additional energy-intensive materials or modifications (Kantatham *et al.*, 2024). Functionally graded concrete (FGC) addresses these issues by reducing cement use in certain regions and replacing it with alternative materials,

lowering the carbon footprint. FGC also enhances durability by allowing a tailored distribution of materials, improving resistance to environmental wear and lifespan. It also optimizes strength and thermal insulation properties by varying material composition across the structure, improving overall performance and energy efficiency (Hoy *et al.*, 2024). These advantages make FGC a promising solution for enhancing sustainability and longevity in concrete applications (Samingthong *et al.*, 2023).

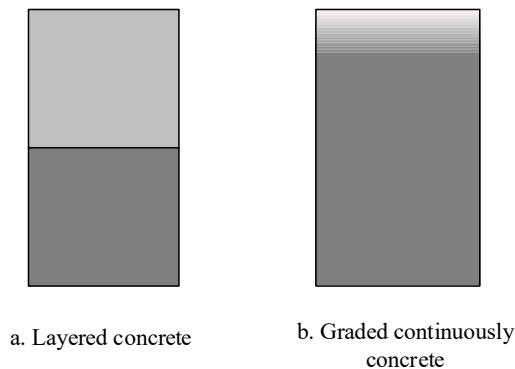
This review compares functionally graded concrete (FGC) production techniques and their performance metrics compared to traditional concrete. It examines layer-by-layer deposition, selective material distribution, and advanced 3D printing techniques, highlighting their advantages and challenges. Key performance indicators include mechanical strength, durability, thermal conductivity, and resistance to environmental factors like moisture, chemicals, and temperature fluctuations.

## Summary of Literature Review

This study of the literature examines functionally graded concrete's (FGC) structural uses, production procedures, design and analytical techniques, and performance improvements. The review papers were taken from (Elsevier, Springer, Taylor & Francis, ieeexplore). Papers were collected from (2019-2023). The study analyzed 49 references related to the growth and performance of functionally graded concrete. The review discusses the production technique, behavior of Functionally Graded Concrete beams, mechanical properties, corrosion durability and Structural Reaction, and cohesive fracture of these concretes.

## Production Techniques and Analysis for Functionally Graded Concrete

Two primary categories of non-homogeneous concrete compositions are layered concrete and continuously graded concrete. A material with a variable composition made up of layers with uniform properties that show a progressive spatial variation in composition is called layered concrete. Continuously graded concrete is defined as concrete with a continuously changing composition. The continually graded and stacked concrete is depicted in Figure 1.



**Figure 1. Diagrammatic representation of (a) layered concrete and (b) continuously graded concrete**

Elemental qualities such as cement reduction, weight reduction, improved post-fracture behavior, and increased durability of concrete elements can all be improved by spatial variation in material composition. This section assesses the potential advantages of functional grading and goes through the design objectives examined for layered and continuously graded concrete.

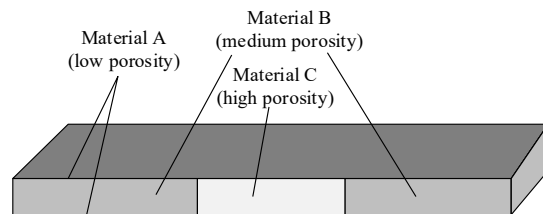
#### Layered graded concrete casting techniques

Based on the casting processes, fresh-on-hardened and fresh-on-fresh casting procedures are the two main types of layered concrete elements. When employing fresh-on-hardened casting, additional concrete layers are applied only after the preceding layers have hardened and set. In contrast, fresh-on-fresh casting involves the simultaneous mixing and casting of many types of concrete. Some of the research articles related to layered graded concrete are reviewed below.

Torelli *et al.* (2020) investigated continuously graded, step-by-step layered concrete systems using various combinations of concrete mixes to attain reduced embodied energy, cost savings, strength, ductility, durability, and fracture resistance. Production methods for both vertically and horizontally stacked components of the structure in the setting of continually graded creating processes as hardened and fresh casting. Functionally graded concrete, which provides a spatially variable material composition to suit performance criteria within structural parts and may reduce cement usage, was becoming more popular as a result of rising global carbon emissions and automation in manufacturing.

Sahoo *et al.* (2022) created the properties of Fresh and Hardened Concrete (FGC), which was formed by stacking techniques. Hardened properties include durability, crack toughness,

elastic modulus, flexural strength, compressive strength, and cross-layer bonding behavior. Impacts of elements such as graded layers, volumetric fractions, surface energy, and stress intensity components. Strength augmentation in FGC was driven by co-extrusion across layer interfaces, which produces a graded layer that performs better than the results of the rule of mixtures. Concrete mixes with high porosity and poor mechanical properties were used in low-stress areas to minimize element mass as shown in Figure 2.



**Figure 2. Multi-layer beam**

Sahoo *et al.* (2021) investigated the creation, characteristics, and geographic modifications in the functionally graded concrete's (FGC) graded layer heterogeneity that was produced by substituting some of the ordinary Portland cement (OPC) with ground granulated blast furnace slag (GGBFS). The FGC specimens were made using GGBFS blended concrete and OPC-based standard concrete, containing concrete layers. With OPC concrete and GGBFS blended concrete as component layers, three different kinds of double-layered cube samples were created in different combinations of layer thickness. When comparing the FGC to the control, the concrete's qualities improved, and the graded layer's development increased the FGC's worth. In order to conduct the experiment, loads were applied perpendicular and parallel to the interface plane between the constituent layers. However, GGBFS concrete's usage in a composite concrete was invisible.

Prasad and Murali (2021a) analyzed the reaction of steel and polypropylene fiber-based Functionally-graded Preplaced Aggregate Fibrous Concrete (FPAFC) falling mass impact. Fibers and coarse aggregates put into an empty mold, a skeleton structure was created in FPAFC, a novel form of concrete. The amount of mono and hybrid steel and polypropylene fiber combinations in twelve different concrete formulations was 2.4%. To determine the most effective combinations to affect FPAFC's resistance performance, two functionally graded schemes were examined. Following the guidelines provided by ACI

Committee 544, 180 cylindrical discs were built and put through testing in the presence of falling masses. However, the optimal amount of fiber blend hybrid and mono fibers may improve FPAFC's impact strength.

Choudhary *et al.* (2020) explored substituting waste rubber tire fibers for natural sand in functionally graded concrete at several volume ratios to enhance the material's qualities. Rubberized functionally graded concrete (FGC) was distinguished by a compositional structure that varies as composition does. When rubberized fiber concrete (RFC), conventional concrete (CC), and rubberized fiber glass concrete (FGC) were compared to each other, their compressive strengths were found to be lower than those of CC. FGC had the maximum flexural strength, however RFC and FGC had greater flexural strength values. Furthermore, concrete reinforced with rubber fibers demonstrated superior resistance to deterioration. Rubber fiber addition has an impact on modified concretes' ability to absorb water.

Haridharan *et al.* (2020) investigated the behavior of the two-layered grouted aggregate fiber-cement composite (TGAFFC) in relation to the glass fiber mesh (GFM) and textile fiber mesh (TFM) combinations. Tests against drop hammer impact were conducted on 21 TGAFFC mixes, which were classified as fibrous and non-fibrous concrete. A combination of GFM and TFM of different diameters occurs between the two surfaces of all fibrous specimens and continuously reinforced with a 3% dosage of 5D hooked end fiber. The outcomes, including impacts number, energy, ductility index, and cracking configuration, Examining test result variances was done with the Weibull distribution; impact representations were displayed using the reliability function. There was currently no research on the effect behavior of TGAFFC in combination with Glass Fibre Mesh (GFM) and Textile Fibre Mesh (TFM).

Murali *et al.* (2021) evaluated resistance to impact in the cement grout injection method on functionally layered two-stage fibrous concrete (FLTSFC). Outside layers of FLTSFC were constructed using steel and polypropylene fibers, which increased resistance and was inspired by turtle shells. The efficiency of one- and two-layered concrete was also examined in the study in order to assess the efficacy of three-layered FLTSFC. It was proposed to use a modified ACI 544 impact test that uses a line-notched specimen rather than a solid cylindrical specimen in order to decrease dispersed findings. The pre-definition of fracture paths was enhanced, and the findings were less scattered as a consequence. The suggested modification resulted

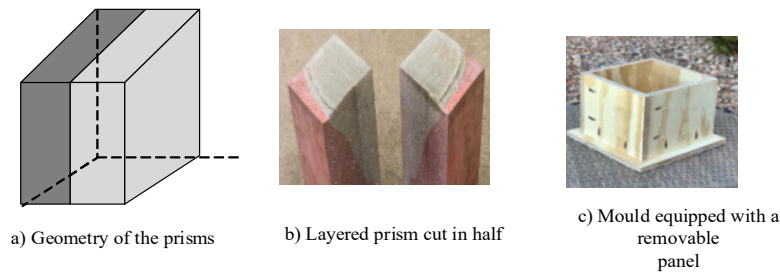
in a significant decrease in scattering, as seen by the ACI impact test's decreased coefficient of variation. Buildings may not sustain much damage from a powerful explosion, but repeated impacts can cause damage and collapse.

Tay *et al.* (2022) examined the relationship between printing parameters and filament material qualities and devised a technique to produce a functionally graded concrete material. The physical properties of the material generated exhibit a strong link with the printer's flow rate and travel speed. 2D optimized concrete construction resulted in over a 50% increase in strength-to-weight ratio, guaranteeing 3D optimization. The main difficulty was getting the three plungers to work together such that the flow at the nozzle's end was constant.

Cao *et al.* (2019) investigated the principles of layered structures, properties of ultra-high performance fiber reinforced concrete (UHPFRC). The influence of layer E-modulus and thickness, and critical load at the first failure stage was predicted using deterministic criteria for layer cracking and de-bonding. After being constructed and tested under three-point bending, double-layered UHPFRC beams were shown to have the best load bearing capacity and beam flexural energy when the layer thickness ratio was 0.6. With peak flexural load reliant on bottom layer fibers and flexural energy enhancement connected to both layers. Since UHPFRC was expensive to produce, its general use was restricted.

Torelli and Lees (2020) investigated the use of casting layered prismatic pieces with a lightweight core section and an outside durability layer to save weight and use less cement. Casting materials concurrently can strengthen the connection between layers. An innovative technique uses simultaneous casting of two concrete mixes to create prismatic pieces with a lightweight core section and an exterior durability layer. To assess the interlayer binding strength, stacked parts of a proof-of-concept prototype were cast with varying pour delays. However, it was feasible to produce components with exterior layers that were wet cast. Prisms of modest size composed of two vertical layers with distinct concrete mixtures were cast using removable panels to separate and contact the materials shown in Figure 3.

Majority of the articles evaluated above are related to Layered graded concrete casting techniques. Due to increased worldwide carbon emissions and production automation, functionally graded concrete was becoming increasingly prevalent. It provides a spatially varied content for structural performance and may also require less cement.



**Figure 3. Two vertical levels of various concrete mixtures comprise the prisms**

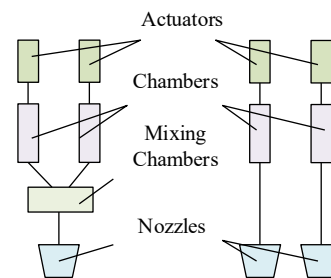
## Continuously graded concrete casting techniques

Continuously graded concrete sections are able to be manufactured automatically due to improvements in robotics. These technologies, which were still in their infancy, have the power to completely change the way concrete was designed and manufactured. Possibilities include controlled segregation methods, graded spraying, and additive manufacturing. Below was an overview of a few research publications on continuously graded concrete.

Li *et al.* (2023) examined to improve the continuously graded steel fiber-reinforced beams' flexural performance. After casting, the fibers were spread across the tensile zone of graded fiber-reinforced beams (GFRBs) through consecutive vibrations. Analyzes the orientation and distribution of fibers as well as the effects of microstructure and fiber reorganization on compressive strength, ultimate flexural strength, first-cracking strength, and flexural toughness index using X-ray computed tomography (XCT). However, XCT for fiber distribution faces challenges due to large steel fibers and limited computer capabilities, including image analysis difficulties.

Ahmed *et al.* (2020) discussed rapid development of additive manufacturing in cementitious materials leads to an innovative design paradigm known as functional grading of material attributes based on location. This can be accomplished by selectively adding fibres or aggregates. This approach can be translated into two methodologies for 3D concrete printing (3DCP): simultaneous process (SP) and repeating sequence process (RSP). Print trials use the equipment for on-demand functional grading. Ductility was shown by the creation of fibre-reinforced 3D printed concrete, showing the possibilities of these technologies. The delay between particle addition and actual deposition at the print head would significantly complicate print planning. The apparatus enables heating, mixing, and extrusion of various materials

from a nozzle, with dynamically varied material ratios achieved through mechanical actuators shown in Figure 4.



**Figure 4. Block schematics of 3D printing machines to produce components with varying functional grades**

Nohut and Schwentenwein (2022) demonstrated the potential of VP approaches in FGM manufacturing, emphasizing that advances in printer technology, software, design, and printing procedures might speed up their adoption. Additive Manufacturing (AM) technologies, particularly Vat Photopolymerization (VP), have gained popularity for the production of Flexible Geometries (FGMs) due to their low cost, high surface quality control, and lack of material constraints. VP, which cures liquid photopolymer resin layer by layer, has grown in popularity due to its inexpensive cost, lack of support structures, and lack of material constraints. Its precision and surface smoothness were limited. Baduge *et al.* (2021) analyzed 3D concrete printing (3DCP) offers the possibility of quick off-site production of intricate structural and architectural elements along with bulk customisation. Important factors affecting the efficiency of 3D printed concrete and strategies for enhancing these characteristics were raised. The methods include novel reinforcement, rheology control, nozzle

design, interlayer bonding, and material modification. The structural elements of 3DCP have the potential to advance technology in the building industry. However, 3DCP faces a number of obstacles, including conflicting rheological needs, inadequate interlayer bonding, integration issues, and anisotropic material behavior.

Pang *et al.* (2022) suggested a unique waterborne epoxy-concrete composite repair material (WECM) that enhances concrete performance by increasing ductility while decreasing flaws such as excessive brittleness and low ductility. Comparing the WECM to the control concrete, the ductility increases by 300%-600%. Enhancement of tensile strength, ductility, and fracture resistance was achieved by the combination of fiber and WEP in WECM. The fiber coating layer, which combines WEP and embedded cement particles, protects the fibers while also improving interfacial bonding. But, concrete alteration was not a defined design or production purpose for WEPs.

Vargas *et al.* (2022) examined existing techniques and procedures for grading the structural qualities of 3DCP, as well as analogous procedures for the possible applications of these ideas in concrete and other 3D printing technologies. Composite materials that avoid discontinuities between layers by gradually changing their characteristics along axes were known as functionally graded materials (FGM). Controlling the spatial arrangement and material composition, three-dimensional printing produces structures with gradable qualities. The complexity of the structure was frequently limited to the shape of the outer shell, which uses a uniform filler matrix.

Kruger *et al.* (2020) developed a constructability design methodology for identifying the fastest vertical building rate by combining print speed and filament layer height. The model was validated using a 3D printed structural wall piece made of concrete. Because high variance in material rheological parameters causes over prediction, a probabilistic design approach attempts to mitigate this effect. Material component factors were found using the first-order reliability method (FORM). However, it cannot provide the best print values for parameters for the realization of objects.

Paolini *et al.* (2019) analyzed the condition of additive manufacturing (AM) in the building industry today, talking about digital planning techniques, systems, applications, and procedures for using AM in research and construction projects along with 3D-printed building materials. Large robotic arm-and gantry systems were used for building additive manufacturing (AM) to create, automate, and optimize materials such as metals,

polymers, and aggregates. However, proper modeling of the construction materials and 3D printing procedures was required.

The majority of the previously reviewed publications discuss methods for casting continuously graded concrete. Substantial work has been done on continuously graded concrete using analytical and numerical methods, but it needs experimental validation. Translating the stated design principles into reality also requires overcoming the inherent limits of existing technology for the manufacturing of continuously graded concrete.

## Behaviour of Functionally Graded Concrete Beam

Accurate evaluation of local stresses and strains was necessary for concrete applications in order to predict damage and fracture paths. Predicting material behavior requires an understanding of local damage and fracture criteria. Since the gradient of elastic properties determines the local stress and strain states, computational models must accurately represent the true spatial distribution of elastic characteristics. Figure 5 shows the types of behavior.

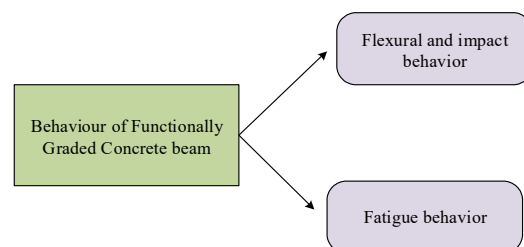


Figure 5. Types of behaviour

## Flexural and impact behavior of Functionally Graded Concrete beam

Flexural behavior of graphite fiber/epoxy laminates composed of bidirectional prepreg materials are examined, with particular emphasis on the impact of hygrothermal conditioned behavior. It considers both hygrothermal ageing defects and the softening effect of absorbed moisture, dividing the first stage into elastic working and transition stages. The research publications on Flexural and impact behavior that have been evaluated are listed below.

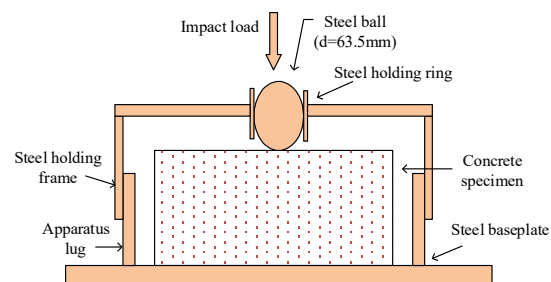
Prasad and Murali (2021b) focused on fabricating steel and polypropylene fibers into functionally-graded two-stage fibrous concrete

(FGTFC) in order to decrease damage and increase impact resistance. Turtle shells' bionic-inspired impact resistance served as the basis for the development of the FGTFC. Three distinct sized FGTFC beams  $250 \times 50 \times 50$  mm,  $400 \times 100 \times 100$  mm, and  $550 \times 150 \times 150$  mm were flexural and impact assessments. In addition to two- and three-layered FGTFC beams, twelve combinations were developed, including Two-Stage Concrete (TSC). The beams were tested against falling mass impact and bending at three points in accordance with the specifications provided by ACI Committee 544. The results showed that impact strength, flexural toughness, and peak load increased with beam size.

Moghadam *et al.* (2021) investigated the impact and flexural behavior of panels made of functionally graded reinforced cementitious composite (FGRCC) with reinforcement consisting of steel and nylon fibers. The outcomes demonstrated that steel fibers outperformed nylon fibers in terms of improving the flexural and impact properties of FGRCC panels. During both experiments, FGRCC panels fared better than RCC panels because of the non-uniform dispersion of fibers.

Sridhar and Prasad (2019) investigated using hybrid fiber-engineered cementitious composites (HYFECC) the damage and dynamic characteristics of functionally graded reinforced concrete (FGRC) beams. In the stress zone, three layers of 25 mm thick HYFECC functionally graded materials were cast into the beams. During bending tests with varying percentage changes in damage levels, one of the beams in each set was found to have cracks in the concrete. By adopting non-destructive technique (NDT) with hammer excitation, important dynamic parameters, were assessed including damping, basic natural frequencies, and mode forms. The dynamical test results for natural frequency and damping values were contrasted with controlling RC beams at every level of damage found during static testing.

Murali *et al.* (2022) examined the functionally graded preplaced aggregate fibrous concrete's (FPAFC) drop-mass impact performance in response to impacts at low velocities. Comparing one- and two-layered concretes, the research makes use of three-layered FPAFCs reinforced with steel and polypropylene fibers. By substituting a steel bar for the steel ball in the modified test, data fragmentation was minimized and impact energy was dispersed over a larger region. The parameters consist of the mechanism of failure, impact numbers, and ductility index. Figure 6 shows a drop-weight impact testing apparatus, ACI 5444.



**Figure 6. ACI Committee's recommended impact test equipment and specimen**

Moghadam *et al.* (2020) investigated the impact strength of slabs of self-compacting cementitious composites used in functionally graded reinforced concrete (FGRC). 1% constant volume steel and nylon fibers were utilized to create 60 slabs, some of the slabs were fully reinforced and others of which were FGRC. The distribution of the fibers was irregular, with an increase in the outer layers and a decrease in the interior layers. Impact experiments using projectiles and drop weights showed that steel fibers had a major influence on the impact strengths of the slabs, whereas nylon fibers had negligible impacts. The behavior of the slabs was enhanced by the irregular distribution of fibers.

Azadeh *et al.* (2021) examined the functionally graded material bamboo's static and dynamic flexural behavior. Its goals include figuring out the way heat affects the Dynamic Flexural Modulus (DFM) and figuring out the Static Flexural Modulus (SFM) of the initial product. Four distinct MOE values during the tensile and compressive states were shown by the static flexural tests in bamboo walls having low and high fiber densities on the inside and outside. The DFM of heat-treated specimens may be established non-destructively using an impulse excitation approach. The impact of varying temperature, duration of exposure, and moisture content on specimen weight and DFM.

Most of the previously evaluated papers address Flexural and impact behavior of Functionally Graded Concrete beam. A HYFECC layer can effectively limit crack widths under service flexural loads, therefore reducing and postponing the entry of hostile materials into stacked beams.

## Fatigue behavior of Functionally Graded Concrete beam

Fatigue behavior in machine components and devices was determined by material resistance, fatigue limit, and proper object design. Geometric shape, processing, and roughness of the surface may all impact stress levels, internal stresses, and fracture formation. Controlling shape, processing, finishing, and environmental aggressiveness, rather than changing the material, may assist to solve fatigue concerns. The research articles on Fatigue behavior that have been assessed are mentioned below.

Su *et al.* (2021) evaluated the ICCP-SS intervention's fatigue performance on corroded beams. It involves 16 RC beams that undergo four-point bending tests after being exposed to ICCP and accelerated corrosion. The intervention greatly improves the fatigue resistance of flexural members and successfully avoids corrosion of the steel reinforcement, according to the results. The fatigue lifetimes of the treated beams were 202% longer than those of the corroded beams. Ruptures in the carbon fiber mesh and the steel reinforcing were the causes of the failure.

Ghorbanpour *et al.* (2021) examined the effect of microstructural anisotropy on the behavior of fatigue fracture formation in Inconel 718 that has been functionally graded and created using laser powder bed fusion (L-PBF). In two construction directions, non-graded and functionally graded specimens were produced using different production settings. The fatigue crack development rate and threshold stress intensity factor were determined using three-point bending fatigue testing. In horizontal samples, the fracture length was consistently increasing, whereas the FCGR value in vertical samples was constant.

Guo *et al.* (2019) concentrated on the fatigue effectiveness of reinforced concrete (RC) structures reinforced using prestressed carbon fiber reinforced polymer (CFRP). The prediction in fatigue life model was created using a progressive damage model that accounts for the steady loss of concrete performance. Projected primary fracture propagation curves and fatigue lifetimes found relatively close to experimental data. Figure 7 displays the mechanism of fatigue failure for both RC and RC-CFRP beams.

Liu *et al.* (2019) suggested improving the fatigue characteristics of orthotropic steel decking (OSDs) by creating a composite deck with massive U-ribs, headed studs, and tiny amount of exceptionally effective concrete. The failure mechanism of the composite deck was exposed, along with the consequences of damage formation in the headed studs and UHPC layer. Examining fatigue resistance requires taking mechanical deterioration into account.

Enfedaque *et al.* (2021) evaluated the flexural fatigue of notched specimens that had been previously broken to achieve Service Limit State (SLS). Between 30 and 70 percent of the pre-crack load was applied in fatigue cycles at 5 Hz over failure or 1,000,000 cycles. The fatigue life of PFRC was much higher than that of SFRC, according to the results. According to fracture surface analysis, the number of cycles that SFRC and PFRC could withstand was directly correlated with the fibers present in the fracture surface.

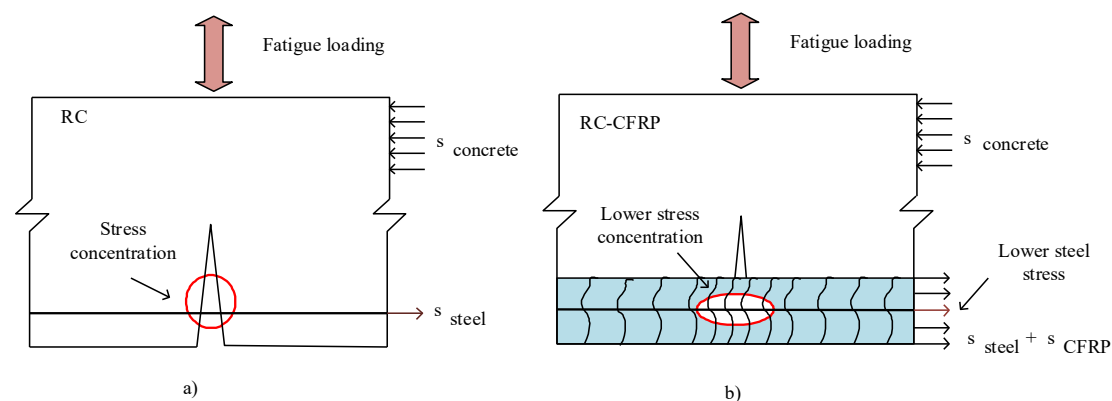


Figure 7. (a) RC beam and (b) RC-CFRP beam fatigue failure mechanism

Slámečka *et al.* (2023) investigated the high-cycle fatigue behavior of scaffolds made of titanium that have characteristics comparable to those of human bone and hierarchical porosity. Direct ink writing (DIW) created the scaffolds that were comparable in normalized fatigue strength against other titanium scaffolds and were able to endure far more cycles than compact strands. In modern biomedicine and other sectors, these structures provide a variety of functions and can safely withstand cyclic stress conditions.

The majority of the articles evaluated above were related to the fatigue behavior of functionally Graded Concrete beams. There was a linear association between the fatigue characteristics of struts and the fatigue strength of titanium lattice structures made using additive manufacturing. The fatigue strength rapidly decreases due to the uneven form of the struts.

### Mechanical properties of functionally graded concrete

Mechanical properties of cracked lining constructions as determined by model testing, numerical analysis, and field research. A computation technique was created to examine the longitudinal cracks affect the carrying capacity of the liner. In order to give a guide for addressing lining cracks in subway projects, the study evaluates the progressive failure law, internal force, and deformation. An overview of a few research that describes the mechanical properties of concrete that has been functionally graded was provided below.

Su *et al.* (2020) examined the degradation laws, internal force, and deformation of linings with prefabricated fractures at various places using three-dimensional model experiments. Based on the results, it was shown that prefabricated fractures enhanced deformation and lowered the lining structure's carrying capacity. Damage was expedited by the fracture's penetration of the vault crown, and structural collapse happened when the crack reached the left arch spring. Prefabricated fractures at the vault caused a rise in deformation and a decrease in the internal forces of the lining structure.

Li *et al.* (2022) used numerical simulation and theoretical research to investigate the mechanical characteristics of functionally graded linings. It investigates the way such features were affected by structural factors such as layer number, Poisson's ratio, compressive strength, thickness, inner radius, and Young's modulus. Additionally, the work provides a formula for calculating maximal

tangential strain and ultimate bearing capacity at lining failure that has been validated by numerical results from simulations. For kilometer-deep subsurface engineering building, functionally graded lining (FGL) was a novel form of rock support designed to fully use the bearing capacity of the lining materials depicted in Figure 8.

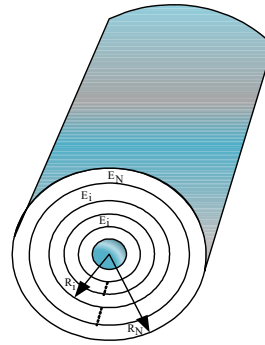


Figure 8. Model of functional graded lining (FGL)

Zhou *et al.* (2020) suggested a parametric design approach to improve the adaptability of triply periodic minimum surface (TPMS) in tissue engineering with changeable pores distribution in functionally graded scaffolds (FGS). Gyroid to produce several FGS varieties, which were made via selective laser melting (SLM). The efficient regulation of the FGS's morphological characteristics suggests that TPMS was a useful technique for creating functional gradients in bone-mimicking structures. In compression testing, FGS performed comparably to the reference FGS with the same density gradient in terms of mechanical reaction.

Zhang *et al.* (2020) analyzed the mechanical characteristics of beams strengthened with low single-layer graphene oxide powders (GOPs) and composed of functionally graded multilayered laminate materials. GOP was more effective at reinforcing the mechanical properties of polymer nanocomposite materials than both single-walled and multi-walled carbon nanotubes, according to parametric tests.

Dai *et al.* (2020) investigated the effects of Portland Cement's (PCC) porosity and cement-aggregate ratio (C/A) on gradation. Increases in C/A or fine aggregate content were shown to be less effective than admixtures. More cement pastes were wrapped with two adhesion admixtures without cement segregation, which led to a higher optimal C/A and more fillers. Comparing three physical fibers to two fine solid wastes, the multi-modified effect was superior.

Jiang *et al.* (2020) investigated the properties of waste glass powder (WGP) containing fly ash-based geopolymer pastes following exposure to high temperatures. The findings indicated that WGP reduced setup time while increasing workability and setting time. The Si/Al ratio was also changed by the inclusion of WGP, which had an impact on mechanical characteristics including compressive and bonding strengths. Additionally, WGP contributed to the geopolymerization process, it produced a more uniform gel matrix.

Wu *et al.* (2019) evaluated the effects of form and steel fiber content on UHPC's mechanical strength, toughness, and shrinkage. The volume fractions of the three steel fiber forms ranged from 0% to 3%. Three bond strengths were assessed: fiber-matrix, flexural, and compressive. Predicting flexural strength included using Composite Theory and a statistical quadratic model. Increased fiber capacity improves flexural and compressive strengths while lowering shrinking. Enhancing the fiber matrix bond and flexural strengths was best achieved using hooked fibers.

The majority of the papers discussed above concentrated on the mechanical characteristics of concrete with functional grading. In locations subjected to extreme mechanical loads or hostile conditions, functional stacking is often employed to enhance the mechanical qualities of structural parts.

## Durability of Corrosion and Structural Reaction

Reinforced concrete structures can be made more durable by using functional concrete gradation, especially in regions where internal steel reinforcement corrosion was an essential problem. The concrete's carbonation and the penetration of corrosive substances like acidic gasses or chlorides are to blame for this corrosion. Initially functioning as a physical barrier, these compounds eventually find their way into pores and fissures in the concrete layer, depassivating the steel reinforcing and resulting in corrosion. These penetrations can be postponed by reducing the permeability, extent, and widths of the cracks in concrete. Few research articles explaining the durability of corrosion and structural reaction was reviewed below.

Tiwari *et al.* (2021) examined the impact of the generic chemicals salicylaldehyde (SA) and triethylphosphate (TEP) on the suppression of corrosion in solutions with carbonated pores that were artificially polluted with chloride ions. According to the results, both compounds lowered the rates of corrosion, and TEP's efficiency increased with concentration, rising from 65.36% to

83.18%. Even at 0.05 M concentration, SA's efficiency reached 96.4%. Phosphate groups were identified in TEP by surface analysis, and SA created a barrier.

Pan *et al.* (2020) examined the corrosion caused by chloride that affects the long-term longevity of concrete constructions. Electrochemical methods were used to investigate the anticorrosion efficacy of migrating corrosion inhibitor (MCI-0). The corrosion resistance of steel rebar was considerably increased by adding an inhibitor, according to the results. The polarization potential of the reinforced bars did not change, and the inhibitor's electrochemical performance was good. The durability of concrete and electrical flux increased by less than 1000 Coulombs when it had 15% compound functional components. However, the electric flow was greatly reduced by the addition of mineral additives and corrosion inhibitor.

Hou *et al.* (2019) examined the corrosion behavior of reinforced concrete/ultrahigh toughness cementitious composite (RC/UHTCC) beams under loading and shrinkage cracking, and their flexural performance after corrosion. Results show that corrosion potential decreases rapidly with chloride solution exposure, while electrical resistance increases over time. Severe pitting corrosion is observed at transverse cracks, causing significant degradation in load-bearing capacity, ductility, bending crack pattern, and deformation. As seen in Figure 9, six strain gauges totalling 100 mm in gauge length were adhered to the surface of beams at the mid-span portion.



Figure 9. Equipment for measuring and setting up flexural tests

Berto *et al.* (2020) investigated corrosion's consequences on two instances of structures constructed in accordance with Italian regulations, taking various corrosion situations into consideration. It evaluates how well a structure performs in harsh environmental settings, taking into account the RC sections' loss of confinement

and the constitutive materials' decreased strength and deformation ability.

Berto *et al.* (2020) examined the capacity to bind chlorine compounds and the resistance to diffuse geopolymer materials systems made with saltwater and coral sand. The permeable nature of C/N-(A)-S-H gel and its high Al material improve its capacity to bind chloride. However, a higher slag fraction results in a higher potential for chloride resistance. Direct assessment is not appropriate for the electric flux approach due to its high variance in the chloride diffusivity.

The majority of the articles evaluated above were related to the durability of corrosion and structural reaction. Functional concrete gradation can enhance reinforced concrete structures' durability by preventing corrosion of steel reinforcement, caused by concrete carbonation and aggressive substances penetration.

### **Cohesive fracture of functionally graded concretes**

Cohesive fracture model that is based on experimental fracture parameters may be utilized for predicting the behavior of fiber-reinforced concrete beams, plain concrete beams, or both. It accurately clarifies the behavior of plain concrete beams. Additionally, it is employed in studies of fiber-reinforced concrete composites that are functionally graded constantly. Below is a review of a few research papers that describe the use of cohesive fracture of functionally graded concretes.

Peyman and Heydari (2020) examined the fracture mechanics of layers of robust aggregate, fiber-reinforced, and plain concrete that are resistant to projectile impact. In addition to a trilinear softening model derived from the traction-separation connection that constitutes the cohesive zone model, it employs a three-point bending test and bilinear softened technique for rough aggregates and ordinary concrete. Numerical analysis uses the extended finite element approach. According to the findings, the homogeneous fiber reinforced concrete model exhibits superior fracture behavior.

De Maio *et al.* (2022) examined the behavior of cracks in reinforced concrete structures within a finite element framework by applying a discrete fracture technique. Through the use of an integrated truss model and an inter-element cohesive model, the simulation predicts the beginning and progression of cracks, simulating the mechanical behavior of rebars made of steel and their interaction with concrete. Real-scale reinforced concrete structural components, the integrated

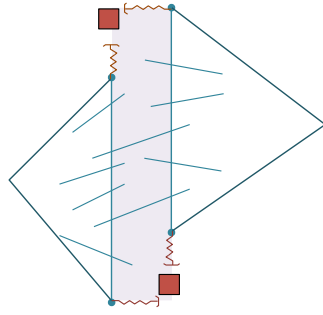
model is utilized to forecast the load-carrying capacity and fracture pattern.

Rahimi and Moutsanidis (2022) demonstrated the capability to accurately and efficiently simulate complicated fracture situations by putting into practice a phase field model for brittle fracture in SPH. The Smoothed Particle Hydrodynamics community limits the use of mesh-based numerical approaches like the finite element method for fracture. Extremely deformed fracture conditions were best simulated using SPH, while earlier models have limitations. Because they may be derived from basic fracture theories and have non-locality, phase field models of brittle fracture have become more and more common.

Chen *et al.* (2022) explored the fracture behavior of asphalt concrete using a finite element model (FE) based on CZM. To create a 3-D internal heterogeneous structure and extract 2-D cross sections for finite element modeling, the model makes use of an image-assisted technique. The model's validity was confirmed by experimental findings and computer simulations of SCB testing. A greater loading rate may result in small element damage because CZM components cannot withstand higher loading rates through deformation. The investigation showed that adhesive elements cause more average damage than cohesive elements at peak load.

Farsi *et al.* (2020) investigated the use of finite-discrete element technique (FDEM) for simulating fracture propagation in tunnels walled with fiber-reinforced concrete (FRC). Three-point bending experimental data was used to introduce and validate the novel FDEM joint-element constitutive model. According to the type of cement and the shape of the tunnel section, it was applied to two instances of tunnel design and displays different behaviors. The features of FDEM contribute to our understanding of fracture behavior and crack propagation in FRC tunnels. As seen in Figure 10, the constitutive laws for the joint elements established in this section may be expressed as the interposition of shear and normal springs between the joint nodes of the components in contact.

Doan *et al.* (2019) examined the validation phase-field technique for Reissner-Mindlin plate theory-based crack plate buckling and free vibration simulation. The approach takes configuration, material qualities, fracture location, and other pertinent assumptions into account while quantitatively examining these occurrences. The phase-field technique represents a substantial advancement for plates with complicated fracture geometries since it can predict both the critical buckling load and vibration mode frequencies.



**Figure 10. Diagrammatic representation of the joint components**

Halakatti *et al.* (2019) suggested a tri-linear model with two kink points for mode-I fracture was based on finite elements to take steel fiber reinforced self-compacting concrete's (SFRSCC) cohesive fracture into consideration. Concrete crack tip opening displacement provides the basis for the following kink point coordinates, whereas the first coordinates were size-independent and derived straight from the model's geometry. Three geometrically comparable sizes were used to test the model, and several nonlinear fracture models were used to estimate the fracture parameters. Two bridging zones within the fracture zone were one for significant fibers and one for tiny aggregates.

The majority of the studies reviewed above were related to the cohesive fracture of functionally graded concretes. Cohesive zone simulations indicate that traction-separation connections diminish with crack opening rather than decreasing to zero. Models that were potential-based and those that were not can be used to categorize these connections. Cohesive energy potential was used in potential-based models, whereas trapezoidal, linear,

bilinear, trilinear, and exponential models were used in non-potential-based models for traction-separation.

## Performance Analysis

Compressive strength, flexural strength, tensile strength, impact ductility index, modulus of elasticity, predicted fatigue life cycle, ultimate bearing capacity, and crack behaviour for functionally graded concrete were determined from various studies. The testing was performed out with Python 3.8, an Intel Core i5 processor, an Nvidia GeForce GTX 1650 graphics card, and 16GB of RAM.

Figure 11 displays analysis of compressive strength. The addition of fibers to concrete has greatly increased its compressive strength, as discussed by four authors A1, A2, A3, and A4. A1 represents Prasad and Murali (2021a) examines graded according to functionality Fibrous concrete with preplaced aggregate (FPAFC) was created from 2.4 % dosage of steel and polypropylene fibers occurs compressive strength as 57 MPa. A2 represents, characteristics of functionally graded concrete can be enhanced by substituting natural sand by 5, 10, 15, 20 and 30% waste rubber tire fibers occurs compressive strength as 40 MPa. A3 as Haridharan *et al.* (2020), explores the use of cement grout injection technique to create functionally layered two-stage fibrous concrete (FLTSFC) achieve compressive strength as 56 MPa. A4 as Ahmed *et al.* (2020), developed fibre-reinforced 3D printed concrete to enhance compressive strength as 40.3 MPa.

**Table 1. shows the comprehensive performance analysis of various studies on functionally graded concrete, highlighting the authors, year of study, methods used, and key findings**

| Author            | Year  | Methods                                                                                                                                                                                                                                                            | Major finding by the authors                                                                                                                                                                                 |
|-------------------|-------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Torelli           | 2020  | Production Techniques and analysis methods for layered and continuously graded elements for Functionally graded concrete                                                                                                                                           | Functional graded concrete can save up to 40% in material costs, and robotics advancements can automate manufacturing, boosting productivity and promoting cement minimisation in the construction industry. |
| Moghadam          | 2021  | The flexural and impact behavior of functionally graded reinforced cementitious composite (FGRCC) panels. Impact response of Functionally-graded Preplaced Aggregate Fibrous Concrete (FPAFC) made with steel and polypropylene fibres against falling mass impact | 1% non-uniformly distributed steel fibers, showed 100.4 times higher impact energy and 27.5 times higher flexural energy than the control panel.                                                             |
| Prasad and Murali | 2021a | Production of Functionally layered two-stage fibrous concrete                                                                                                                                                                                                      | Three-layered TSFC-SF specimen showed a 59.5% higher compressive strength, while three-layered FGTFCC specimens exhibited a 5.2 to 54.4%.                                                                    |
| Murali            | 2021  |                                                                                                                                                                                                                                                                    | Three-layered FLTSFC exhibited excellent post-crack resistance, ranging from 2.98 to 6.79.                                                                                                                   |



Figure 11. Analysis of compressive strength

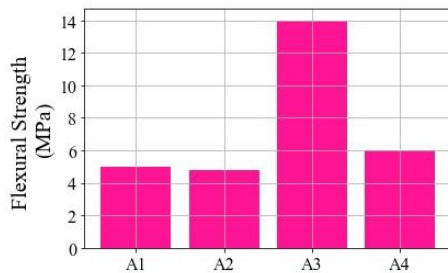


Figure 12. Analysis of flexural strength

The analysis for flexural strength is shown in Figure 12. According to four authors (A1, A2, A3, A4), adding fibers to concrete has significantly boosted its flexural strength. A1 as suggest that replacing natural sand with waste rubber tire fibers can enhance the functionally graded concrete properties, resulting in a flexural strength of 4.97 MPa. A2 as Ahmed *et al.* (2020), have developed fibre-reinforced 3D printed concrete with a flexural strength as 4.8 MPa. A3 as Li *et al.* (2023) aim to improve the flexural performance in continuously graded steel fiber-reinforced beams with 2% and 0.3% volumetric fiber content. Achieve flexural strength as 14 MP. A4 as Baduge *et al.* (2021) examines fibre reinforced 3DCP for structural applications has a flexural strength of 6 MPa.

Figure 13 displays the analysis for tensile strength. Four authors (A1, A2, A3, and A4) discussed tensile fracture behavior in concrete-based materials using cohesive zone models, expressing tensile strength against crack opening width. A1 as Peyman and Heydari (2020) conducted fracture mechanics the first notch exists, the projectile impact-resistant concrete which includes plain, fiber-reinforced, and strong aggregate layers presents a three-point bending test. Tough aggregate concrete is characterized by its high tensile strength as 3.19 MPa. A2 as Umberto De Maio *et al.* (2022) investigates the behavior of cracks in concrete, aiming to remove the hypothesis of e-cracks for accurate analysis. It occurs tensile

strength as 1.96 MPa. A3 as Farsi *et al.* (2020) investigates the application of the finite-discrete element technique (FDEM) to fracture propagation simulation in tunnels lined by fiber-reinforced concrete (FRC), and it has a tensile strength of 3 MPa. A4 as Halakatti (2019) suggests a tri-linear model with two kink points for mode-fracture in steel fiber reinforced self-compacting concrete (SFRSCC) achieves tensile strength as 4.38 MPa.

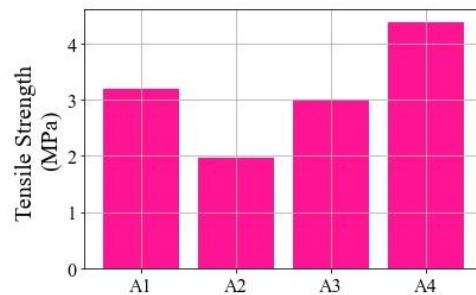


Figure 13. Analysis of tensile strength

The analysis for impact ductility index is shown in Figure 14. Four authors (A1, A2, A3, and A4) examined two-stage fibrous concrete with functional grading and its impact response. A1 as M.K. Haridharan *et al.* (2020) examined the behavior of the grouted aggregate fiber-cement composite (TGAFCC) compared to glass fiber mesh (GFM) and textile fiber mesh (TFM) combinations. Impact ductility index of TGAFCC was 3.49%. A2 as Gunasekaran Murali *et al.* (2021) examines the use of the cement grout injection method to create two-stage fibrous concrete that is functionally layered (FLTSFC). All fiber specimens were found to have index ductility values ranging from 6.79 %. Using steel and polypropylene fibers to create functionally-graded two-phase fibrous concrete (FGTFC) with a significant ductility index of 11.8% is the main goal of A3, according to Prasad and Murali (2021a). A4 as Gunasekaran Murali *et al.* (2022) examines the effect that changing drop-mass effects on functionally graded replacement aggregate fibrous concrete (FPAFC). Impact ductility index of FPAFC was 6.44%.

Figure 15 displays the analysis for the modulus of elasticity. The elastic modulus of concrete changes due to accumulative damages during repeated fatigue loading discussed by authors A1, A2, A3, and A4. A1 as Guo *et al.* (2019) evaluate the fatigue resistance of reinforced concrete structures reinforced with prestressed carbon fiber reinforced polymer (CFRP), occurs modulus of elasticity as 35.2 GPa.

A2 as Saeede Ghorbanpour *et al.* (2021) studied the fatigue crack growth behavior of Inconel 718 by laser powder bed fusion (L-PBF), has modulus of elasticity was 36 GPa. A3 as Liu *et al.* (2019) suggests thin ultra-high-performance concrete layers and headed studs to improve the fatigue properties of OSDs. Achieves modulus of elasticity as 42.1 GPa. A4 as Alejandro Enfedaque *et al.* (2021) evaluates the fatigue behavior of steel and polyolefin fiber-reinforced concrete post-cracking, achieves a modulus of elasticity as 34.1 GPa.

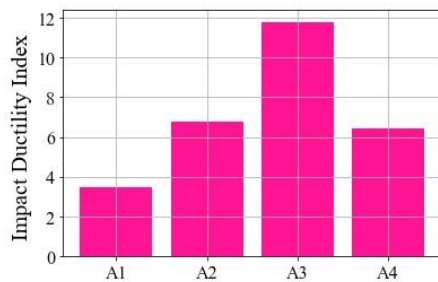


Figure 14. Analysis of impact ductility index

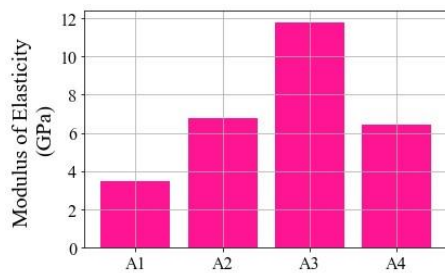


Figure 15. Analysis of elastic modulus

The fatigue life cycle analysis is shown in Figure 16. Authors A1, A2, A3, and A4 discussed that the dimension of the aggregate bonding surface and the quantity of layers both enhanced the fatigue life. A1 as Su *et al.* (2020) evaluates the fatigue performance of corroded beams supported by ICCP-SS intervention predict fatigue life cycle as 175. A2 Guo *et al.* (2019) as assessed the fatigue resistance of reinforced concrete structures made of prestressed carbon fiber reinforced polymer (CFRP) predict fatigue life cycle as 203. A3 as Liu *et al.* (2019) examines the use of headed studs and thin, ultra-high-performance concrete layers to improve OSD fatigue characteristics, predict fatigue life cycle as 180. A3 as Karel Slámečka *et al.* (2023) examines the high-cycle fatigue behavior of titanium scaffolds with hierarchical porosity predict fatigue life cycle as 278.

Figure 17 displays the ultimate bearing capacity. Authors A1, A2, A3, and A4 discussed ultimate bearing capacity, which is the bearing stress that causes a sudden catastrophic shear failure. A1 as Su *et al.* (2020) examines the mechanical properties of functionally graded multilayer nanocomposite beams, which occurs ultimate bearing capacity as 60 MPa. A2 as Li *et al.* (2022) suggests proposes a gradient-varying FGL has radially Young's modulus, has ultimate bearing capacity as 35 MPa. A3 as Zhou *et al.* (2020) proposes a parametric design method to enhance the adaptability of triply periodic minimum surface (TPMS) has 90.52 MPa ultimate bearing capacity. A4 as Jiang *et al.* (2020) examined the effects of high temperatures on waste glass powder (WGP) containing ultimate bearing capacity of 53.22 MPa.

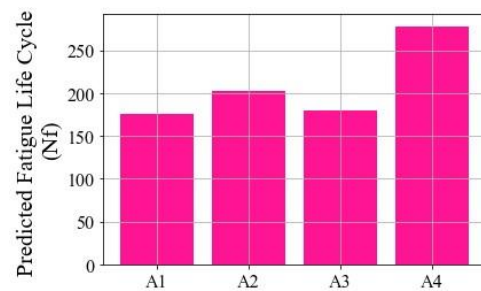


Figure 16. Analysis of fatigue life cycle

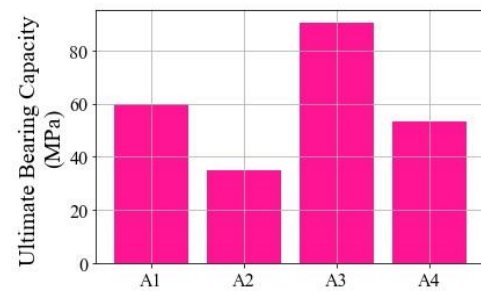


Figure 17. Analysis of ultimate bearing capacity

Figure 18 shows a crack behavior analysis. The cracking behavior was thoroughly examined by calculating crack width and crack spacing, as discussed by Authors A1, and A2. A1 as Rahimi and Moutsanidis (2022) create a phase field model of brittle fracture within the context of SPH, occurs crack behaviour in 1.5 mm. A2 as Chen *et al.* (2022) used a CZM-based finite element model (FE) to examine the cracking process of asphalt concrete, has crack behaviour for 3.5 mm.



**Figure 18. Analysis of crack behavior**

Table 2 shows the FGC's performance metrics compared to traditional concrete, highlighting its superior properties. Functionally-graded Preplaced Aggregate Fibrous Concrete (FPAFC) exhibits a compressive strength of 59 MPa, which is more than double that of traditional concrete at 28 MPa, due to its higher fiber content (2.4%). The flexural strength of rubberized functionally graded concrete is 4.97 N/mm<sup>2</sup>, slightly higher than traditional rubber fiber concrete (4.4 N/mm<sup>2</sup>), showing improved resistance to bending forces. Most notably, The IDI value of the one-layer TSFC mixture beams varied from 2 to 10%, indicating poor post-crack resistance. In contrast, functionally-graded two-stage fibrous concrete (FGTFC) exhibited strong post-crack resistance, with IDI values ranging from 4 to 11.8%. These enhancements make FGC a robust choice for demanding structural applications and environments.

**Table 2. FGC's performance metrics compare to traditional concrete**

| Property               | Author                           | FGC<br>(Functionally Graded Concrete) | Traditional Concrete  |
|------------------------|----------------------------------|---------------------------------------|-----------------------|
| Compressive Strength   | Prasad and Murali (2021a)        | 59MPa                                 | 28MPa                 |
| Flexural Strength      | Choudhary <i>et.al.</i> , (2020) | 4.97 N/mm <sup>2</sup>                | 4.4 N/mm <sup>2</sup> |
| Impact ductility index | Prasad and Murali (2021a)        | 4-11.8%                               | 2-10%                 |

## Future Scope

Since the inception of FGC, extensive research has been conducted by distinguished researchers, focusing on the design, modeling, fabrication, characterization, and review of various parts of the procedure. The focus has been on the fabrication of FGC, the characterization of FGC s, and the fabrication of FGC s. The literature also includes extensive studies on the fabrication and characterization of FGCs. Since the discovery of FGC, significant progress has been made in resolving issues with crucial engineering materials, and ongoing research is being conducted to provide suggestions for future research.

Homogenization of particulate FGC is critical because of particle contact. Theoretical models frequently differ with observed FGC constant values, highlighting the necessity for a probabilistic method to adjust for variations in the distribution of materials across the amount. This method facilitates an accurate evaluation of material qualities.

Analysis of the response, fatigue, and fracture properties of FGC structures in the instance of a probabilistic homogenization issue requires the application of probabilistic mechanics.

Although FGM manufacturing processes are widely used, further study is necessary to ensure a consistent and dependable distribution among the phases and properties of the substance's constituents inside the construction

FGM materials' strength and resistance to fracture are strongly influenced by thermal residual stresses. In manufacturing techniques without layered structure, residual stresses arising from temperature mismatches should be taken into account on a macro-mechanical and microscopic level. It is essential to analyze macro-mechanical residual stresses resulting from various layers and thermal expansion coefficients.

Temperature has an impact on material qualities as well as stress, stability, and vibration issues in FGM. Even when the material is treated to consistent temperature, certain material phase is more sensitive to temperature changes than others, then changes in properties could not occur consistently throughout.

## Conclusions

Concrete was the world's most frequently used construction material, accounting for 5% of global carbon emissions from cement production. A critical assessment of Functionally Graded Concrete (FGC) was provided in order to reduce cement and concrete consumption while keeping their inherent strength and durability. The structural applications, manufacturing procedures, and methods for analysis and design were the main topics of the review. Concrete comes in two main topologies as layered and continuously graded. Functional gradation of concrete can save up to 40% in material costs and time. This involves reducing cement content, controlling post-fracture behavior, using low-permeability materials, minimizing the cracking, and optimizing thermal performance. Technological developments in robotics can automate the production of Continuous Graded Concrete (FGC), revolutionizing both architectural design and the construction sector. Methods for fresh-on-fresh casting provide a strong link among layers and a shorter production time. Gradient spraying, rotation-controlled segregation, and additive manufacturing can all produce continuously graded concrete. Superior impact energy absorption, a robust interfacial bond, excellent fiber utilization efficiency, and compressive strength were all displayed by the material. According to this review study, functionally-graded Preplaced Aggregate Fibrous Concrete (FPAFC), which contains 2.4% steel and polypropylene fibers, performed well with a yield of 57 MPa for compressive strength. Considering two-phase fibrous concrete (FGTFC) composed of steel and polypropylene fibers, the impact ductility index is 11.8%. The fatigue characteristics of OSDs are improved by ultra-high-performance concrete layer and headed studs, possess a modulus of elasticity of 42.1 GPa. Cracking behavior was detected in asphalt concrete using a CZM-based finite element model (FE), with crack behavior lasting for 3.5 mm. However, control of wet-on-wet FGC elements remains a challenge. Further research is needed to understand these properties. The precast industry may utilize current structural analysis tools to predict functionally stacked fresh-on-fresh concrete, however this is dependent on the layer interface integrity. Preferential paths for aggressive drug diffusion, areas of weakness or interface cracking might be dangerous. The properties that affect the bond between layers in fresh-on-fresh casting require more investigation. This might lead to safer design of optimized concrete buildings and increased production.

However, advanced modeling methods and specific knowledge are required for a successful structural investigation into continuously graded concrete buildings. The creation of basic analytical techniques to simulate FGC has the potential to influence a shift toward cement minimisation in the building sector.

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**Availability of data and material.** Not applicable.

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**Author contributions.** The corresponding author claims the major contribution of the paper including formulation, analysis and editing. The co-author provides guidance to verify the analysis result and manuscript editing.

**Compliance with ethical standards.** This article is a completely original work of its authors; it has not been published before and will not be sent to other publications until the journal's editorial board decides not to accept it for publication.

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