2024 Scienceline Publication

Journal of Civil Engineering and Urbanism

Volume 14, Issue 4: 405-422; December 25, 2024 ISSN-2252-0430

DOI: https://dx.doi.org/10.54203/jceu.2024.43

Glass Fiber Reinforced Concrete in Construction: A Review of Advances, Challenges, and Future Prospects

Hamza Baybure

Istanbul Aydin University, Faculty of Engineering, Department of Civil Engineering, Istanbul, Turkey

Corresponding author's Email: hamzabaybure@gmail.com

REVIEW ARTICLE

PII: S225204302400043-14

Received: November 11, 2024

Revised: December 22, 2024

Accepted: December 23, 2024

ABSTRACT

In this study, the material compliterosition, mechanical strength (tensile strength, bending strength), alkali strength and durability properties of glass fiber reinforced concrete (GRC) and its sustainable place in construction technologies are evaluated based on a review of the literature. GRC is a composite material that stands out with its high mechanical performance, which is widely used especially in facade elements. In the research, it has been found that glass fibers positively affect the mechanical performance (tensile strength, bending strength) of concrete by preventing the formation of cracks in its microstructure, and its resistance to aging and environmental factors increases with pozzolanic and nanomaterial additives. In addition, the effects of fiber type, fiber content and fiber dimensions on GRC performance were compared; the gains achieved in both environmental sustainability and mechanical properties through the use of recycled materials and waste materials were emphasized. Experimental and theoretical studies in the literature have shown the increasing importance of GRC in the modern construction sector.

Keywords: Glass reinforced concrete, Mechanical properties, Durability, Nano materials, Pozzolanic materials, Water/ conjugate ratio, Micro crack development

INTRODUCTION

Glass fiber reinforced concrete (GRC) is a preferred material especially for facade elements, prefabricated building elements and various construction applications (Maraşlı et al., 2023). The use of glass reinforced concrete, which has been used for a long time in the production of special design mechior walls, often comes before us İskender et al., 2018; Mohamed Ahmed Berrani et al., 2022a). It has a more flexible structure compared to traditional concrete and shows high tensile strength thanks to the glass fibers contained in it (Maraşlı et al., 2023). Concrete is the most widely used construction material in the world, and in order to highlight some of the missing aspects of this material and some of the features we want, we can produce our concrete with glass fiber reinforcement and produce it for special requests and needs (Blazy et al., 2022; Yildiz & Bölükbaş, 2010; Toklu et al., 2022). Glass fiber reinforced concrete consists of cement aggregate water and glass fibers randomly distributed in the concrete (Ardahanli et al., 2023; Yıldız et al., 2010; Yurdakul et al., 2014). This type of glass reinforced concrete is commonly used as precast, that is, elements that are used as facade elements that are brought to the site where the installation will be completed and manufactured elsewhere without being manufactured on site (Maraşlı et al., 2023; Mohamed Ahmed Berrani et al., 2022b). In addition, it is frequently used in industrial and industrial production. Today, the wind type is defined as the primary excuse for the production of wings and its use in this area is about 150 thousand tons (Hassan & Saeed, 2024). Glass fiber reinforcement prevents the formation of microcracks that occur in the concrete at an early stage and significantly contributes to the tensile strength and bending behavior of concrete (Ardahanli et al., 2023; Yildiz & Keleştemur, 2000).

Barhum and Mechtcherie (2012) performed a uniaxial pressure test on the test samples in order to investigate the effects of alkali-resistant glass and carbon-reinforced short fibers on the fracture behavior of concrete manufactured by adding. As a result of this study, the stress-shapeshifting curves clearly showed the positive effect on the mechanical performance of each GRC. In addition, various degrees of matrix-fiber bonding were observed

To cite this paper: Baybure H (2025). Glass Fiber Reinforced Concrete in Construction: A Review of Advances, Challenges, and Future Prospects. *J. Civil Eng. Urban.*, 14 (4): 405-422. DOI: https://dx.doi.org/10.54203/jceu.2024.43

depending on the water-binding ratio of the matrix (Barhum & Mechtcherine, 2012). Sarıbıyık et al. (2013) have carried out this experimental study in order to improve the basic properties of materials such as strength and resistance. In this study, it was determined that the amount of resin used in GRC production and quartz aggregate powder used as filling material were %10, %20, %30, %40 and the effects on the workability and compressive and flexural strengths of concrete produced by replacing waste glass powder at a rate of 47% have been investigated. As a result of the studies, an increase in the amount of resin used in polymer concrete has also been achieved, as well as an increase in the pressure and flexural strength of concrete. As a result, significant increases in the pressure and surface strength of concretes have been detected (Saribiyik et al., 2013).

An experimental study by Banthia et al. (2014) shows that of the four main requirements for any repair material, reinforced fiber meets all of them: First, it can stop further deterioration and especially corrosion of reinforcement and is sufficiently impervious to liquids and gases. Secondly, it can bond properly with old concrete and restore structural integrity. Thirdly, it is durable and can withstand severe climatic conditions. Finally, it has chemical, electrochemical, permeability and dimensional compatibility with the repaired old substrate (Banthia et al., 2014). In this experimental study conducted by Butler et al. (2010), it was carried out to examine the time-dependent changes in the mechanical performance of the GRC made with AR glass fiber and to determine the Decisive mechanisms affecting the durability of this composite material. Their samples were subjected to accelerated processing, tested under stress during and after aging periods of different durations. Depending on the matrix composition, various degrees of strength and tensile capacity loss were observed. In the study conducted by Yilmaz and Glasser, the reaction and durability of alkali-resistant glass fibers with cement were investigated (Yilmaz & Glasser, 1991). In Otto's study, the relationship of tensile strength of glass fibers with diameter was examined. As a result of the study, when fibers of different diameters are formed under controlled, almost identical conditions, their breaking strength is the same within experimental limits, and the diameter has no significant effect (OTTO, 1955).

Rabea Barhum and Viktor Mechtcherine consider the effect of adding short fibers made of alkali-resistant glass on the fracture behavior of textile reinforced concrete (TRC). A series of uniaxial, deformation-controlled tensile tests were performed to observe the strength, deformation and fracture behavior of thin, narrow plates made of TRC with and without the addition of short fibers. In addition, multi-filament yarn tensile and single fiber tensile tests were performed to better understand the crack bridging behavior, which suppresses crack growth and expansion. Various effects of short fiber addition on the stress-shape change relationship of TRC and cracking behavior have been observed (Pastor et al., 2014a).

Pastor et al. (2014a) aim to evaluate the inclusion of waste tires in Glass Fiber Reinforced Concrete panels in order to reduce the amount of sand by reusing a recycled material, thereby providing a double ecological benefit. At the same time, it is an acoustic insulation of this material. As a result of the study, it has shown the benefits of replacing it with a recycled material, i.e. tires; thus, a double ecological benefit has been obtained without affecting the production procedure. The rubber additive causes a decrease in mechanical performance, which has been described extensively in rubberized concrete, and it has been observed that this can be compensated by the addition of nanosilica additives (Kizilkanat et al., 2015a). Kizilkanat et al. (2015a), have analyzed the comparative use of glass fibers as fiber reinforcement in high-strength concrete. In the test results, it was observed that there was no significant effect on the compressive strength and elasticity modulus of different types of fibers. As a result of this study, while the tensile strength of separation increased with increasing fiber dosage, no increase was observed in the strength of glass fiber reinforced concrete (GFRC) beyond 0.50% fiber dosage. The flexural strength, similar to the tensile strength of separation, gradually increased with increasing fiber content, but no such change was observed for GFRC after a fiber content of 0.50% (Marasli et al., 2022).

In this study, it is aimed to conduct a review study about the existing studies in the literature. Research studies conducted in the form of subheadings taking into account the different properties of GRC (glass fiber reinforced concrete) will be summarized.

MATERIAL COMPOSITION OF GRC AND CHEMICALS

Definition and development of GRC

GRC (glass fiber reinforced concrete) is a kind of composite concrete with glass fiber content. GRC has been contributing to the construction industry for more than 40 years in architectural and engineering applications because it has a positive tendency against corrosion and tensile strength compared to traditional concrete (Iskender et al., 2018). The use of glass as a building material was realized in the 1940s. Due to the nature of glass, it was very difficult to use it together with alkaline concretes. Because of this, glasses with high alkali resistance were made in the 1960s. During this time, glass fibers took their place on the market commercially. By the 1980s, the GRC composites made were significantly high in mechanical strength and were produced in accordance with the standards (İskender et al., 2018).

In addition, in order to provide an original design opportunity and reduce the structure weights, efforts have been made to search for solutions that will reduce the cross-sectional thickness of concrete and increase its strength. As a result of the studies carried out, glass fiber reinforced concrete (GRC) elements began to be used in the construction sector at the end of the 1960s and are still widely used today (Yıldız, 2022).

The effect of pozolanic additives and materials

Glass fiber reinforced concrete (GRC) concretes are strong in many mechanical properties. In the concrete environment, glass fiber is negatively affected by corrosion with aging. It has been observed that these effects (modulus of rupture, toughness index...) are reduced by the addition of nanosilica and methacoal (pozzolonic materials) due to aging and decrease in strength. Madhkhan & Katirai (2019a) showed the effects of pozzolanic additives on the aging of glass fiber fibers due to time in their study. Different pozolanic material (silica fume, methacaolin and nano silica) and glass fiber fibers have been used for GRC production. Due to aging, the toughness index and rupture modulus decreased over time. The use of metacaolin has been effective in reaching the highest values of mechanical properties in GRC. But in another study, although the same results were found for pozzolanic materials in general, they found a different result for methacaolin. Gutiérrez Melgarejo et al. (2019) have conducted a study with the aim of reducing and preventing damage due to aging with pozolanic additives and materials. They ensured the aging process by immersing in hot water at 50°C with a humidification and drying cycle. Improvements in mechanical behavior have been observed with the use of 3% polymer by weight in industrial pozolanic materials. The greatest aging-related deterioration was observed in hot water aging at 50°C. 40. It has been observed that it occurs per day. An increase of flexotraction resistance of 20 MPA was observed compared with the control sample without addition. GRC has a proportional effect on the resistance of composites to polymers with mixtures of GRC, while pozolan (methacaolin) has the opposite effect (Gutierrez Melgarejo, 2019). In another study, observations were made in such a way that very similar results were obtained with the other two studies. Genovés et al. (2015), investigated the main topics of fiber modification and making it more resistant to high alkaline environment, matrix modification by adding a medium amount of pozzolanic powders that partially replace the content of portland cement, fiber and matrix modification at the same time. In the literature review of the study, it was stated that successful results were obtained in GRC mechanical strength by partially replacing the cement with reactive mineral additives such as silica fume, fly ash, methacaolin or blast furnace slag. In the study, samples consisting of cement, fly ash, water, superfluidizer and glass fiber were prepared and tested. When we look at the mechanical results, the sample compressive stress is higher with a lower water binding ratio. The bending strength is higher in the sample with a high water/binder ratio. It is more brittle because a harder matrix will be obtained in a smaller proportion of pozolanic material (Genovés et al., 2015).

Pozolanic materials and additives (silica fume, blast furnace slag, methacaolin, fly ash, etc.) It generally has a positive effect on the mechanical strengths on GRC concretes. In addition, it has been observed that it also reduces the strength decreases in mechanical properties due to aging.

Nanomaterial doped GRC

GRCs have much better properties compared to conventional concrete in most subjects, and nanomaterial additives are used to make these properties better and to better respond to specific requests. We are able to achieve positive effects such as increasing resistance to corrosion, increasing mechanical strength, removing surface defects with very small amounts of nanomaterial additives.

Maraşlı et al. (2023) have produced carbon nanotube integrated concrete together with alkali-resistant glass fibers. They used two different carbon nanotubes, single-walled (SWCNT) and multi-walled (MWCNT). They carried out the tests of the GRCs they produced with these nanomaterials with 5 test samples, including one reference, and tested their physical properties in the test results. As a result of the test, a significant increase in the machinability of the SWCNT integrated GRC was observed and its contribution to strength was observed by acting as a bridge for micro-roofs. The best results were observed in composites with 0.01% heavy SWCNT added (Subasi et al., 2022). SEM images of single-walled carbon nanotubes are given in Fig. 1. Another study, Gao et al., (2008), the mechanical effects of a nanometer-scale hybrid coating layer based on styrene-butadiene copolymer containing single or multi-walled carbon nanotubes (SWCNTs, MWCNTs) and nanocylls were investigated. Significant improvements in both mechanical and environmental corrosion resistance of GRCs have been observed with the contribution of nano-reinforced resin at low rates. The best mechanical improvement results were observed in nanotube coated glass fibers. As a result, composite nanocoats cause an increase in fiber strength, an increase in corrosion resistance and an improvement in interface properties, Gao et al. (2007), have produced nanocomposite coated GRCs in order to improve the alkali resistance of glass fibers and eliminate surface defects. Improvements in both environmental corrosion resistance and mechanical properties of conventional GRCs have been observed with the addition of nanotakewires at low rates. These results are valid in the alkali-resistant glass fiber and E-glass fiber used in the study (Gao et al., 2007).

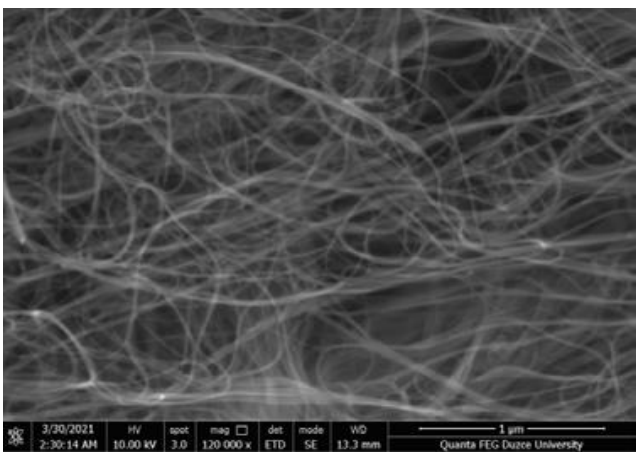

Figure 1. Swcnt SEM IMAGE (Subasi et al., 2022).

The effect of fiber differences on GRC

The biggest differences between GRCs from conventional concrete are the glass fiber reinforcements added to them. These supplements may contain fibers of different sizes, proportions and types (alkali-resistant glass fiber, etc.). These contents affect the characteristics of GRC. Deghan et al., glass fiber reinforced concrete samples were produced at the rates of o%, 1%, 2% and 3%. They tested the mechanical strengths of the samples such as pressure, bending and contraction with samples produced according to the fiber quantities. As a result of this study, when the compressive strengths were examined, an increase in the strength ratios of 1%, 2%, 3% and 3% compared to the non-fiber sample, an increase of 3%, 10% and 6% was observed, respectively. Bending strengths are 56 with the first days. Compared to the day, there seems to be a greater positive effect. Again, it showed a positive trend by 55%, 60%, 83% and 96% in non-fiber, 1%, 2%, 3% fiber reinforced concrete samples, respectively. The consistency of this study was observed when compared with other existing studies in the literature (Maraşlı et al., 2023). Similar situations are also observed in concretes that fall into the glass GRC category in samples with a different content. Ali & Qureshi (2019) tested the mechanical strength of recycled aggregate-containing concrete samples by adding glass fibers in determined proportions. In this study, cylindrical samples (150mm × 300mm) were used for pressure test, while a prism (100mm × 100mm × 500mm) was used for bending strength. Glass fiber fibers were selected at the rates of 0%, 0.25%, 0.5% and 1% and samples were prepared. On the other hand, a positive increase has been observed in the compressive strength, even if it is not too much. The maximum increase in compressive strength was observed in the concrete sample containing 0.75% glass fiber, an increase of 6%. When the bending strength was examined, a positive increase of 26% was observed in the samples with a glass fiber contribution of more than 0.25%. Separation was not observed after the first cracks formed during the tensile experiment. This situation shows the high amount of positive contribution of glass fibers to ductility. Ali et al. (1975) tested samples were created using glass fiber fibers of different lengths (10 mm and 40 mm) and alkali resistance between 2% and 8% by volume and compared with concrete produced decently by conventional method as a reference. They observed the best mechanical GRC behavior in samples with a length of 40 mm (Ali et al., 1975). As a result, glass fiber reinforcements show a generally positive effect on the mechanical properties of concrete. Fiber content and length have an effect on these mechanical strength properties; it has been observed that the use of glass fiber in the optimal ratio and length increases the compressive strength of concrete, also improves ductility and crack control. However, the fact that the fiber content is too high leads to a negative effect in terms of workability. Therefore, the performance of the GRC can be maximized by optimizing the amount and length of fiber.

The effects of water/conjugate ratio on GRC

The GRC water/binder ratio is among the factors that affect the mechanical properties the most decently. It affects GRC workability, fiber distribution and matrix microstructure. The effect of Zhu Yuan and Yanmin Jia on the mechanical strength and microstructural properties of glass fiber in their study was experimentally studied by examining the ratio of water binder depending on the fiber content. Two different samples were obtained by determining the water binding ratios as 30% and 35%. The mechanical strengths of concrete (pressure and bending) were tested on a 7- and 28-day basis. Considering the compressive strength in terms of water binder ratios, while samples with a water/binder ratio of 30% in GRC samples at 7-day compressive strength give better results. (7-day sample 28MPa (w/b 30%)-22.9MPA(w/b 35%)) Pressure test results of 28-day samples showed higher compressive strength than GRC samples with a water/binder ratio of 35% (Yuan & Jia, 2021). Zhen et al. (2024), as a result of tests conducted on 60 samples, they obtained the best mechanical strength results with a fiber content of 0.2%-0.3% with a water/ binder ratio of 48% in early concrete strength. GRC also creates differences in the microstructure of the water/binder ratio these differences can cause positive or negative effects. When looking at the SEM results in the study conducted by Ahmad et al. (2022), the optimal fiber content depends on the water/binder ratio. When we look at the effects of the increase in the water/binder ratio and the effects of fiber content on pore size and microstructure caused by the effect of combining, this ratio is at an important point.

According to the researches, it is seen that the water/binder ratio is significantly effective in the mechanical strength and microstructure properties of GRC. The water/binder ratio to low ratios increases the GRC compressive strength and also positively affects the bending strength, but the fact that this ratio is low reduces the workability. It negatively affects the strength by increasing the porosity at high rates. Attention should be paid to this optimal value in the GRC design.

Fresh concrete behavior of GRCs

The behavior of GRC fresh concrete depends on variables such as the ratio of glass fiber and water/binder ratio, especially properties such as workability and shrinkage (Barluenga & Hernández-Olivares, 2007). In his study, Hernández-Olivares took a concrete sample produced by the traditional method as a reference sample, and samples were created using two different types of glass fibers and the behavior of fresh concrete was tested comparatively. By adding 600 g/m3 of glass fiber to the samples, free drying at an early age reduced shrinkage and crack area by 50% to 90%, but this alone is not enough for crack control. When looking at the crack lengths, they decreased significantly in concretes with fiber addition. But we cannot draw the correct proportional conclusion. No difference was observed between the fibrous and the reference sample at shrinkage Decrements. As a result of these data, glass fiber fibers limit the growth of cracks caused by drying and shrinkage by air flow in fresh concrete and have a positive effect on the crack control capacity (Barluenga & Hernández-Olivares, 2007). There are multiple factors that affect the behavior of fresh concrete, some of which are water/binder ratio, fiber content ratio. The effect of Zhu Yuan and Yanmin Jia on the mechanical strength and microstructural properties of glass fiber in their study was experimentally studied by examining the ratio of water binder depending on the fiber content. Two different samples were obtained by determining the water binding ratios as 30% and 35%. Concrete mechanical strengths (pressure and bending) were tested on a 7- and 28-day basis. If the behavior of fresh concrete is considered Decently, fresh concrete between 10% and 15% is weaker than 28-day GRC concrete compressive strength (Yuan & Jia, 2021). Similar results have been found in other articles on this subject. Ali et al. (1975) in the study where they examined various parameters of GRC and performed their tests by producing 10 different GRC samples, they observed that when GRC is fresh, its workability is low compared to conventional concrete, but it increases its mechanical strength (Murthada et al., 2019). In the experimental studies conducted, we reach the conclusion that glass fiber negatively affects the workability of fresh concrete, but it shows a positive effect mechanically. GRC has been observed to have free drying at an early age, shrinkage and a decrease in cracks.

MECHANICAL STRENGTH OF GRC'S

GRC tensile and compressive strength

When we look at the studies in the literature, Zhu Yuan, Yanmin Jia, when we look at the mechanical strength of GRC in their study, the mechanical strength shows about 20% to 25% higher compressive strength of GRC when we look at the compressive strength of GRC with a concrete sample produced by the classical method. Dec. When we look at the bending strengths, it can be said that the fiber content increases as it increases, but when it exceeds the optimal level, the strength decreases. It is as effective in the ratio of water/binder as the fiber content has an effect on this. When looking at the samples with a water / binder ratio of 30%, the best results for bending strength were given by samples with a bending strength of 7 MPa and a fiber content of 1.35%. A sample with a water-to-binder ratio of 0.9% and a water-to-binder ratio of 35% yielded 6.41MPa. The separation has shown similar results in tensile strength (Yuan & Jia, 2021). Kizilkanat et al. (2015b), carried out their experiments by gradually increasing the fiber content by keeping the water/binder ratio constant. The glass showed no change in compressive strength until the fiber content exceeded 0.5%. An increase in strength was observed in GRC samples with a fiber content above 0.5%, and they found the highest compressive strength in the sample with a fiber content of 0.75%. A very small decrease in bending strength is observed when the fiber content exceeds 0.5% in GRC samples (Kizilkanat et al., 2015b). GRCs are composite structures that allow concrete to improve in terms of mechanical strength compared to traditional concretes created by adding glass fiber fibers. Fibrous concretes are superior to non-fibrous concretes in terms of mechanical behaviors such as separation, tensile and compressive strength. Ali et al. (1975), an increase in flexural strength up to 5 times and tensile strength up to 20 times compared to non-fibrous concrete GRC samples produced with 6% fibers by volume with a length of 30 cm was observed in 28 days, an increase in flexural strength up to 5 times and tensile strength up to 20 times (Ali et al., 1975). As a result, GRC is superior in terms of bending, compressive and tensile strength compared to conventional concrete. Significant increases have been observed with the optimal fiber content. In addition, the GRC water/binder ratio is also effective, as is the amount of fiber, and should be balanced. If it is balanced, an increase is observed mechanically in the same way. As this is mechanical, the positive increase is clearly seen in the tensile and flexural strength, while there is no such increase for the compressive strength.

Table 1. Review and comparison of relevant studies

Fiber content (%)	Compressive Strength (MPa)	Flexural Strength (MPa)	Tensile Strength (MPa)	Reference
0 (Referans)	22.9 - 28.0	4.0	2.5	Yuan & Jia, 2021
1	23.6 - 28.8	6.2	2.7	Maraşlı et al., 2023; Yuan & Jia, 2021
2	25.2 - 30.8	7.3	2.9	Maraşlı et al., 2023; Yuan & Jia, 2021
3	24.3 - 29.7	7.8	3.1	Maraşlı et al., 2023; Yuan & Jia, 2021
0.25	23.0	5.0	-	Ali & Qureshi, 2019
0.5	23.5	5.8	-	Ali & Qureshi, 2019
0.75	24.3	6.3	-	Ali & Qureshi, 2019
1	24.0	6.5	-	Ali & Qureshi, 2019
0.2-0.3	24.5-25.0	-	-	Zhen et al., 2024

GRC ductility and energy damping property (Capacity)

GRCs are composites developed to improve the brittle structure and mechanical properties of conventional concrete. Glass fiber fiber additive delays the crack propagation of concrete, improves its ductility and energy damping capacity. Ali et al. (1975), test samples were created using glass fiber fibers of different sizes (10 mm and 40 mm) and between 2% and 8% by volume and compared with concrete produced decently by conventional method as a reference. When evaluated in terms of elastic behavior, an increase in elastic behavior was observed up to a fiber content of 6% by volume, and there was not much effect on this value (Ali et al., 1975). The study conducted by Cheng et al. (2024) focuses on the flexural behavior and energy damping properties of Glass Fiber Reinforced Concrete (GRC), particularly emphasizing the impact of varying glass fiber content in the concrete matrix. The research reveals that the toughness of GRC is significantly enhanced due to the effective integration of glass fibers, which increases the pull-out energy and fracture energy during tensile loading. The experimental results indicate that as the glass fiber content increases, the fracture energy exhibits a marked increase, suggesting a direct correlation between fiber volume and the material's ability to absorb energy under stress. Additionally, the results highlight that GRC can exhibit improved ductility, making it suitable for applications requiring materials with both strength and flexibility. The findings advocate for the use of optimized glass fiber content in GRC to achieve the desired structural performance under flexural loading while enhancing its energy damping capabilities GRC plays an important role in ductility and impact absorption, mechanical strength, as well as optimal fiber level, as well as optimal impact contributions. In the study conducted by Ambroise et al. (1989), the effect of metacaolin additive was studied in order to improve the long-term ductility and strength properties of GRC. When traditional potrland cement is used in GRC construction, the strength decreases in terms of mechanical properties and the glass fibers undergo deterioration due to the alkaline environment. This causes an increase in fragility in the GRC. To investigate the ductility of GRC, the work of fructure and index of toughness were measured with energy-based parameters, and mixtures containing 40% methacaolin showed an increase in ductility and energy absorption. As can be seen from the studies conducted, glass fiber fibers are very effective in increasing the ductility and energy damping capacity of concrete. The optimum value of the fiber content can be accepted for ductility as 6% when looking at the references. In addition, methacaolin prevents the deterioration of glass fibers by increasing the chemical resistance in the structure of the matrix, and has a positive effect on long-term ductility and energy damping capacity and bending strength.

GRC fatigue behaviors

GRC is a preferred building material in the construction sector due to its high strength and ductility.

GRC service life is decreasing due to reasons such as degradation of glass fibers in alkaline environment and microstructure defects, and it is important to predict service life and predict strength losses. There are effective methods such as accelerated aging test with hot water to predict GRC strength loss. In addition, pozolanic additives and nanomaterials significantly improve the GRC aging performance. In the study conducted by Purnell (2001a), he presents a modeling to estimate the service life of glass fiber reinforced cement (GRC) components using accelerated weathering with hot water. It is derived by considering the mechanism of micro-mechanical strength loss. It has adapted well to all available strength versus time data of different GRC formulations. The strength loss of GRC is mainly due to the weakening of glass fibers over time. This weakening is associated with the growth of micro-defects on the fiber surface over time (static fatigue). The developed model has been confirmed by data obtained from accelerated aging tests in hot water. Different pozolanic materials are added to make the GRCs better mechanically. As these lead to an improvement in their mechanical properties, their effects on aging, aging-related toughness and rupture are also seen as positive. Murtaza Madhan and Roozen Katirai have tested the mechanical effects on aging in GRC samples produced with two different production types and added pozolanic additives in their study. during the period of 7 to 90 days, the rupture modulus of the GFRC samples decreased due to damage to the fibers in the concrete matrix. The largest decrease in the rupture modulus occurred in the short term (7- to 28-day period), and this decrease was more pronounced compared to the 28- to 90-day period. The use of pozolanic materials in their samples slows down the rate of reduction of the rupture modulus over time. This situation allows the loss of strength of the material during the aging process to be more controlled. In the studies conducted, it has been determined that the highest break modulus value in both the short and long term is observed in mixtures containing 15% methacaolin. This indicates that metacaolin makes a positive contribution to the aging performance of GRC. Although GFRC mixtures containing nano silica initially experience a decrease in the breaking modulus, the performance of these samples during the aging process is remarkable. comparisons after 90 days revealed that the reductions in the modulus of rupture of nano-silica-containing designs were less radical. This situation can be attributed to the extensive pozolanic reactions that occur in the presence of nano-silica. These reactions produce a high amount of cemented gel, minimizing the damage to the glass fibers over time, thereby increasing the long-term durability of GRC (Madhkhan & Katirai, 2019b). As a result, it has been observed that the main cause of GRC mechanical strength loss is the growth of micro defects on the surfaces of glass fiber reinforcements over time and the static fatigue mechanism. The models developed in accelerated aging tests allow to successfully predict the strength loss of differently manufactured GRCs. Pozolanic additives and nanomaterials increase the durability of GRC over long periods of time by reducing the reduction rates in the rupture modulus. GRC with a methacaolin content of 15% and GRC with nano silica reinforcement have a significantly positive effect on performance during the aging process.

Fracture mechanics

GRCs show twice as much fracture strain performance compared to conventional concretes. Different pozolanic materials and additives are added to GRCs to provide an increase in fracture strain and fracture strength (Enfedaque et al., 2010). Kizilkanat et al. (2015b), observed a significant increase in fracture energy when the glass fiber content exceeds 0.25% compared to conventional concrete GRC fracture behavior. As the fiber content increased, the GRC samples showed a better performance in terms of breaking energy. Ali et al. (1975), in their experiments with GRC samples with an increased fiber content up to 8% fiber by volume, the fracture and impact resistance are directly proportional to the fiber content. The sample with a glass fiber content of 6% by volume provided 15-20 times better impact resistance than the non-fiber sample. In a similar study, similar results were obtained about GRC in an experiment conducted with different additives, different glass fibers and different examination methods, and it was interpreted that the additives had a positive effect. Enfedaque et al. (2015), GRC refractive energy was tested with techniques that serve to obtain test results in both vertical and parallel directions. Additives such as matever powerpozz were used, which caused to increase the GRC fracture energy. in experiments performed by adding 25%, the metaver slightly increased the refractive energy in the parallel direction, while it was more effective in the perpendicular direction. Powerpozz, on the other hand, has increased its breaking energy by 4 times. Multiple cracking in perpendicular fracture has not been observed in any samples. DIC (correlation to digital imaging) was used to study GRC fractures. In general, most of the GRC samples showed a limitation in damage distribution. Thanks to the micro-effects of GRC fiber additives, it shows a very good performance against fracture compared to conventional concrete. As an example, the sample with a fiber content of 6% shows a high performance of 15-20 times compared to conventional concrete. It has been observed that this strength can be increased more with chemical additives and pozolanic additives.

GRC DURABILITY AND RESISTANCE TO ENVIRONMENTAL INFLUENCES ERE

Effects of freezing thaw

GRC provides significant advantages in terms of its structural durability and resistance to environmental influences. The effects of freeze-thaw cycles on material performance are important, especially in cold climates. The studies carried out aim to optimize this durability in the long term. Using samples created using alkali-resistant glass fibers made by Enfedaque et al. (2012), performed experiments using freeze-thaw resistance as 25 freeze-thaw cycles, which were cooled to -20 °C for 2 hours and dissolved in +20 °C warm water for 2 hours. after 50 cycles, the GRC samples experienced a loss of 40% bending capacity and 80% strain capacity. . The effects of freezing thawing are being tested by creating cycles under different conditions, a similar study by Yang et al. (2024) the different glass fiber contents of recycled concretes during the production of GRC samples (%0-,%1, %1.5) as samples are produced. at the end of 150 freeze-dissolution cycles, a sample with a fiber content of 0.5% had a mass loss of 0.405%, an increase in compressive strength of 8.19%, a sample with a fiber content of 1% had a mass loss of 1,100%, an increase in compressive strength of 21.35%, a sample with a fiber content of 1.5% had a mass loss of 0.725%, an increase in compressive strength of 17.79%. The optimum fiber level was observed as 1%. Glass fibers absorb stress during the compression of concrete, preventing the formation of microcracks and reducing surface distortions. According to the Weibull distribution model, it has been observed that the freeze-thaw resistance of GRC with a fiber content of 1% is clearly higher compared to conventional concrete. Similarly, the freezing and thawing effects are in the GRC's weather resistance test task. The freezing and thawing resistance of concrete is greatly improved by adding glass fiber fibers, and it also shows the same positive effect on the dry shrinkage of concrete (Xiaochun et al., 2017).

Resistance To Corrosion And Carbonation

How the long-term performance of GRC is affected by environmental factors, especially carbonation and corrosion, is an important safety issue. For this reason, it is necessary to test the material with different aging conditions. Cheng et al. (2019), GRC samples with fly ash and slag content were examined by performing natural curing for 28,180 and 360 days and accelerated aging at 80 C for 8 days. there were no problems with the 28-day samples and they showed successful results in terms of toughness and bending. In the same way, corrosion was not observed in the 180-day-old samples. However, corrosion has been observed in 360-day samples. Even if the glass fiber strength decreases due to corrosion in 360-day GRC samples, an increase in GRC strength has also been observed due to an increase in the strength of the matrix. In addition, Qin Xiaochun et al. (2017), examined the situation of using GRC as a road coating to study the corrosion mechanism. Oct. Even in the case of alkali resistant glass fiber corrosion, the final bending strength of glass fiber samples was obtained higher than non-glass fiber samples despite the fact that the glass fiber was corroded Carbonation also develops in the same way as corrosion depending on environmental factors and time, and they affect the GRC in similar ways. In relation to this, Purnell et al. (2001b) have experimentally investigated this situation in their studies related to the carbonation of glass fiber reinforced concrete. The aged standard GRC samples completely deteriorated (carbonation), but some samples retained their toughness (48%, 58% and 71% carbonated) some tensile strength increase was observed. In addition, Amg Senevirante et al. (2002) have examined the size differences and environmental effects that occur during carbonation in their study. The samples produced are continuously subjected to a cycle of wetting with water and drying and exposure to the open air. During the carbonation process, expansion was observed in GRC samples and this is the opposite of the natural carbonation state. Carbonated samples are less resistant to swelling and shrinkage. This experiment is an indicator for the use of GRC in humid environments. Although environmental factors such as carbonation and corrosion have a negative effect on GRC mechanical strength and microstructures, when looking at the studies conducted, matrix strength and fibers can maintain overall strength.

GRCs can gain hydrophobic properties with the help of different additives and turn into a technological anti-corrosion building material. Doğan and Dehghanpour (2021), the hydrophobic properties of cementitious mortar surfaces coated with silicone-based composites containing TiO_2, ZnO, and recycled nano carbon black (RNCB) in different proportions were compared to protect building materials. To evaluate the surface performance of the hydrophobic samples, Scanning Electron Microscopy (SEM), Energy-Dispersive X-ray Spectroscopy (EDS), X-ray Diffractometry (XRD), 3D surface profilometry, surface roughness, and contact angle measurements were carried out. The results revealed that the particles were homogeneously distributed on the surface of the mortar in all hydrophobic samples. It was determined that the amount of TiO_2 and ZnO particles in the crystalline phase had a significant effect on crystallite size and lattice strain. The ZnO–S2 sample exhibited strong hydrophobic behavior with a water contact angle reaching up to 155°. However, the RNCB–S2 sample, with a contact angle of 145°, was shown to have significant potential for low-cost hydrophobic surface applications. The highest uniform surface roughness distribution (4.33 µm) was recorded in the ZnO–S sample, while the closest value (3.47 µm) was observed in the RNCB–S sample. This study aimed to prevent liquid ingress into the porous structure of cementitious materials by forming a hydrophobic coating on the mortar surface. In particular, the hydrophobic effect of RNCB particles on the cementitious surface is believed to play an important role in reducing the wettability of cement-based materials (Doğan & Dehghanpour, 2021). Morphological images of the relevant study are given in Figure 2.

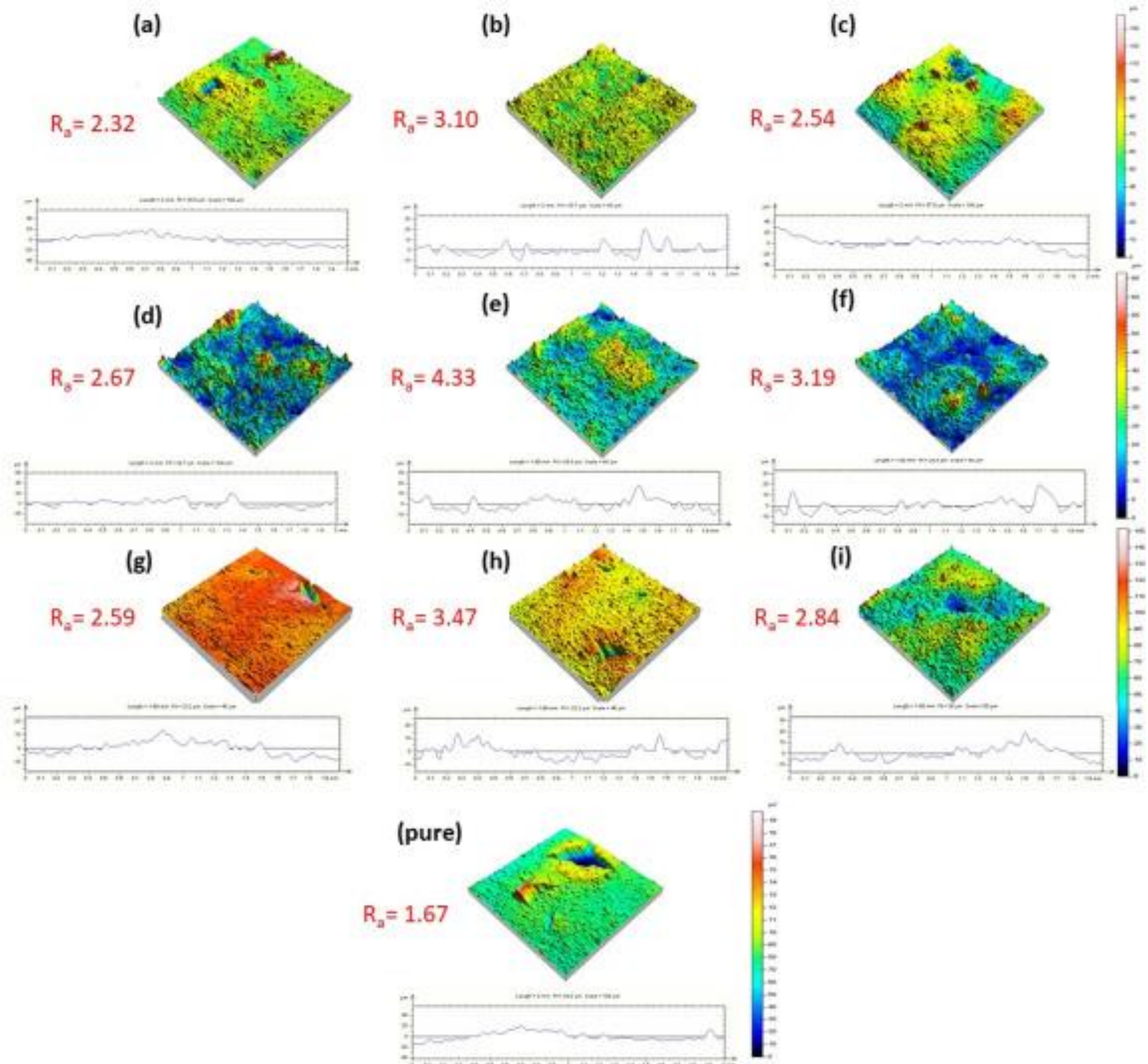

Figure 2. Surface topographies and roughness distributions of untreated mortar (pure), TiO_2–S (a:0.10 g, b: 0.15 g, c: 0.20 g), ZnO–S (d:0.10 g, e: 0.15 g, f: 0.20 g) and RNCB-S (g:0.10 g, h: 0.15 g, i: 0.20 g) samples at 2 mm scanning area, respectively (Doğan & Dehghanpour, 2021).

Resistance to High Temperatures

When concretes are exposed to any high temperature, there are disadvantages and negative effects in the maintenance of mechanical properties (Georgali & Tsakiridis, 2005). In his study, Ahmet Çavdar, the cement matrix starts to deteriorate at 450 °C and completely deteriorates and cracks at 650 °C. As temperatures begin to rise, their bending strength decreases. This decrease in bending strength was observed by 76% at 450 °C, 87% at 650 °C in conventional concrete, approximately 60% at 450 °C and 88% at 650 °C in GRCs. Their compressive strength decreases in the same way (Çavdar, 2012).

Resistance of GRC to aging and chemical degradation

When examined in general, GRC performs much better in the aging state and against chemicals than conventional concretes. Although some studies have been done for different purposes, it has been examined in this case. Enfedaque et al. (2011), they carried out tests on both fresh and aged samples while examining the damage and impact behavior of GRC facade panels. In this experiment, we see the effects of aged GRC on impact behavior. The GRC samples were aged by immersion in water at 50 °C for 40 days. A sharp difference between young and Decile GRC behavior could not be observed. In other words, in the experiment, young and old GRC samples slow down the bullet by an equal amount for any impact speed. As a result, the aging behavior performance of GRCs is successful in terms of impact absorption. Pozolanic material additives also have an effect on aging and mechanical strength. Madhkhan & Katirai (2019a) have tested the aging and mechanical properties of GRC produced with three different pozolanic materials (silica sand, silica fume and methacaolin) and alkali-resistant glass fiber with two different production methods (pre-mixing and spraying) in their study. It was observed that there was a decrease in the toughness index and breakage modulus over time due to aging. Pozolanic additives reduce the compressive strength in wet samples, while increasing the pressure was observed in aged samples, and the highest compressive strength was observed in the aged sample with methacaolin additives. The same result was observed in the rupture module. While the specific breaking modulus of cement Decays between 7-90 days, the pozolanic materials increase it (Madhkhan & Katirai, 2019c). In concrete production, the matrix medium with a pH value above 12 is not preferred when it will damage the glass fiber reinforcement. But later, this problem was eliminated with the production of alkali-resistant glass fiber. Orlowsky et al. (2005) investigated the effect of alkali resistant fibers on this environment in alkaline solution with a pH value of 13.5 and at a temperature of 50 ° C and without any load and obtained 45-day test results. A decrease in tensile strength of up to about 60% and thinning of fiber diameters were observed in the samples. As a result, GRC makes it an ideal material in construction industry applications due to its aging resistance, chemical stability and mechanical performance supported by pozzolanic additives.

GRC micro crack development and imaging

In general, microfibers are primarily responsible for mitigating the initiation and propagation of cracks in cementitious composites. By bridging microcracks at an early stage, they enhance the material's tensile behavior and contribute to improved durability and long-term performance. Numerous studies have demonstrated that the inclusion of microfibers can significantly control shrinkage-induced and flexural cracking, especially in brittle cement-based matrices. Thus, microfibers play a critical role in improving the integrity and service life of cementitious materials (Dehghanpour et al., 2022). SEM images obtained from the development studies of Dehghanpour et al. on the CNT–CF–Al2O3-CMC gel-based cementitious repair composite are given in Fig. 3.

In glass fiber reinforced concretes (GRC), their mechanical properties deteriorate over time, some tests can be performed to predict these distortions. After the tests performed on early and old GRC samples on samples in the laboratory environment, their structures can be examined by observation methods such as SEM, XRD, TGA and FTIR, and thanks to them, the effects of factors such as chemicals used, different fiber lengths can be observed on young and old samples. With these methods, fiber-matrix interface and microcrack Decrements can be examined. Enfedaque et al. (2010), microstructures of broken surfaces were analyzed using scanning electronic microscope (SEM). In the experiment, the mechanical strengths of the numenes with different contents and their microstructures were examined by SEM with tensile testing on the samples. As a result of the experiment, it was found that metacaolin had a positive effect on the microstructure, but it was not enough for fragile behavior for aged GRC. Irregular fracture surfaces were obtained only when testing the GRC in the early stages of its life. Even the broken surfaces have appeared large glass fiber rupture. It has been tried to find optimal values by producing different samples with different experiments and examining its microstructure. Muna & Eman (2012) reported that the addition of glass fiber to concrete and mortar increased the separation tensile strength for concrete and mortar by up to 12.5% and 17%, respectively. The increase has been attributed only to the bridging action of fibers along the cracks, which initially limited the fracture of microcracks. The tension is transferred to the bridging fibers after the bending damage, and these cracks prevent its rupture for a while, and thus the tensile strength of separation increases. There are similar results with similar studies. In this case, it proves the accuracy of this event to us, and the most important element that allows us to achieve this is the methods and equipment that allow us to study the microstructure. In study of Barluenga & Hernández-Olivares (2007), samples were added by adding 600, 900 and 1000g/m3 alkali-resistant fibers to conventional non-fiber concrete, and the added fibers were marked with ink so that they could be observed with a microscope. Two positions have been observed between the cracks and fibers, and they are such that they are parallel and perpendicular. Dec. A micrograph of a crack crossed by several glass fibers perpendicular to the crack edges and forming bridges limiting crack growth was observed through an optical microscope. Studying the fiber structure helps us to see the long-term events of GRC behavior in different situations and in different scenarios. Purnell et al. (2001b) on GRC carbonation, they were able to examine the microstructure of aged samples with carbonation with TSM (thin section microscope) and make a visual comparison. In the examinations, it was concluded that the reason for the higher bond appearing in the carbonated samples was the closer following of the fiber strand of the matrix. In summary, microstructure analysis methods play a very important role in order to predict GRC mechanical distortions and improve material performance.

Carbon fiber and alkali-resistant (AR) glass fiber differ significantly in composition, mechanical properties, and durability. Carbon fibers are composed of carbon atoms arranged in a crystalline structure, offering high tensile strength, stiffness, and excellent electrical conductivity. In contrast, AR glass fibers are composed of silica-based glass with zirconium oxide, designed to resist alkaline environments like cement matrices. While carbon fibers provide superior mechanical and electrical performance, AR glass fibers are more cost-effective and chemically compatible with cementitious materials, making them ideal for concrete reinforcement. Sample SEM images obtained from carbon fiber and glass fiber reinforced cementitious composites are given in Figure 4.

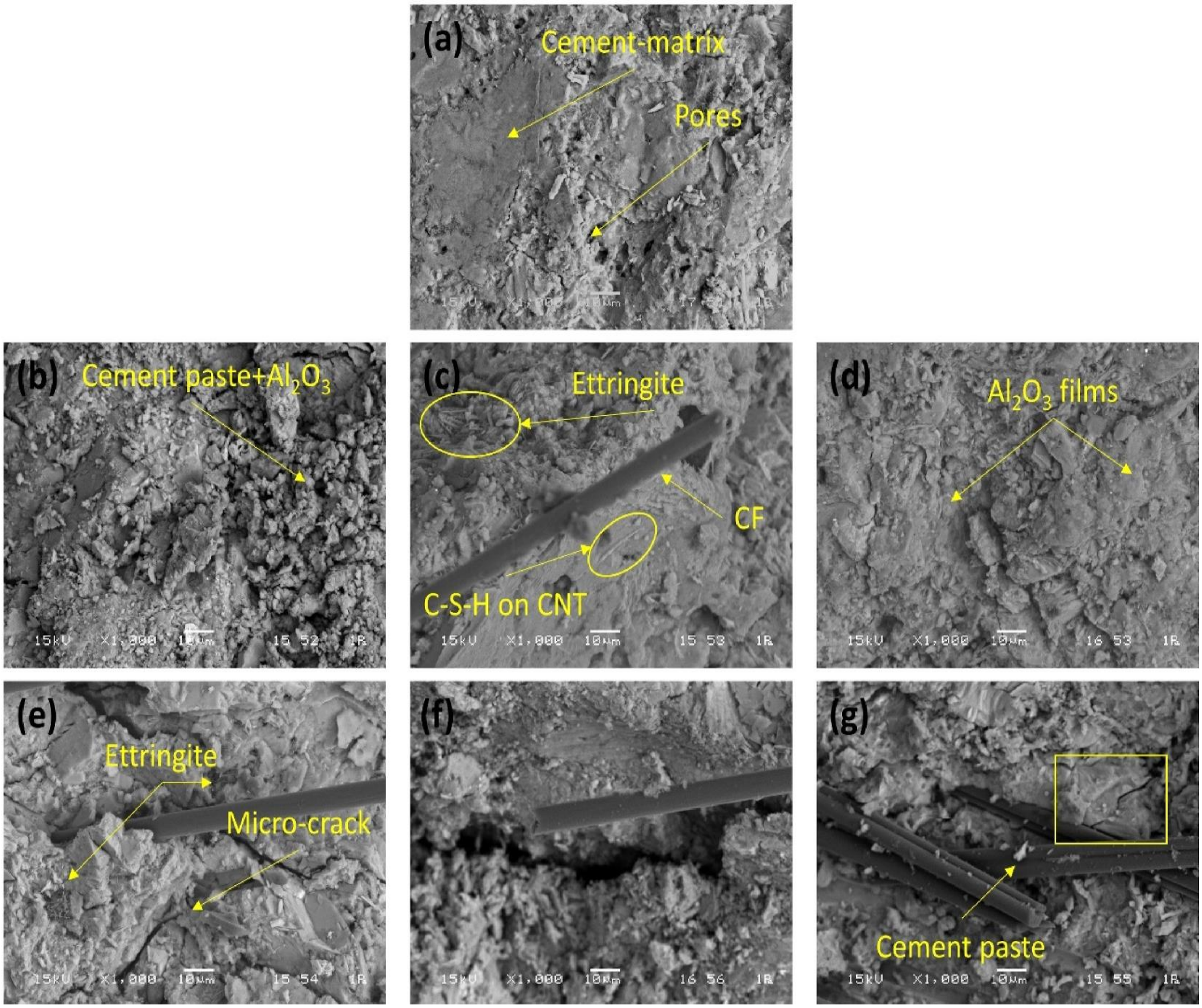

Figure 3. SEM images of CBRC with different cementitious composition (Dehghanpour et al., 2022).

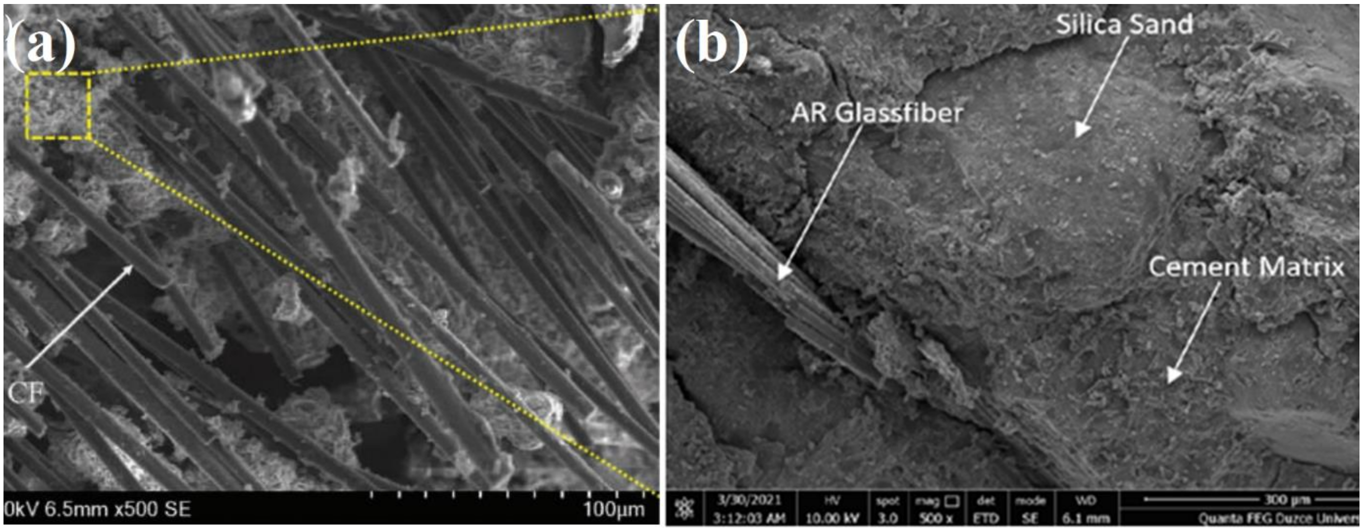

Figure 4. a) Sample SEM images obtained from carbon fiber (Doğan et al., 2022) and glass fiber (Subasi et al., 2022) reinforced cementitious composites.

PRODUCTION APPLICATION RHEOLOGY

GRC rheological properties and workability

GRC is a preferred composite material type in the construction sector due to its high strength and ductility properties. However, GRC workability has an important place in the fresh state due to its rheological behavior, ease of application and performance. Jiao et al. (2019) have done their studies on the effects of rotational cutting process on the rheological behavior of short glass fiber fresh mortar. The effects of different cutting speeds, durations and increase rates on the fluidity and viscosity of the mortar were tested. An increase in the shear rate significantly changes the interaction of fibers and particles in the internal structure, which directly affects their properties, which change due to fluidity. This study shows that the rheological behavior of fresh GRC changes depending on the applied rotational cutting conditions and this has a direct impact on the machinability. The effects of rheological properties on workability decrease as the fiber content increases with the collapse times (Güneyisi et al., 2019). The GRC workability is directly proportional to the fiber content. It has been observed that GRC, which has a glass fiber content of 1.5% compared to conventional concrete, leads to an increase in collapse flow and V-funnel flow times (Servet et al., 2010). It was observed that the torque value increased in the same comparison with the rheometer test. If the balance between mechanical strength and workability is, C30 was extensively studied about its mechanical strength and workability by adding glass fibers to concrete in different proportions. With the increase in the glass fiber additive ratio, there is a decrease in workability. In the samples produced, the mixing and settling times of the samples with a fiber content of 15 and 20 kg/m3 were extended. Despite this, the compressive strength increased by 2.5% and the tensile strength increased by 8-15%. According to the studies conducted, the rheological properties and workability of GRC vary greatly depending on the proportion of glass fiber used and the mixing conditions applied. Mechanical effects such as rotational cutting directly affect the viscosity of fresh mortar, and workability decreases as the fiber content increases. However, this situation can be balanced with the optimal use of fiber.

The Effect of Grc Curing Conditions on Performance

Lalinde et al. (2022), carried out this experimental study in order to test the durability of GRC samples containing a high proportion of pozolanic additives. For GRC curing conditions, first of all, standard curing process was performed for 28 days in a room with 20°C and 90% relative humidity, and secondly, curing was performed by immersion in water for 7 days at 20°C and 21 days at 55°C. By having a humid curing condition in a long-term and controlled manner, it ensures the complete realization of pozolanic reactions. In this way, the porosity in the matrix decreases, its microstructure tightens and prevents the degradation of glass fibers in an alkaline environment. Lack of moisture during the curing process can cause crack formation at an early stage and crack the fiber-matrix bond. Under optimal curing conditions, it is observed that the bending and compressive strength of GRC increases, while the freeze-thaw and chemical resistance resistance decreases. In addition, it provides fiber matrix adherence in a way that prevents the spread of microcracks Lu et al. (2022) on the effect of curing temperatures on performance, hydration reactions are accelerated at high curing temperatures (50-80°C), which increases pressure and bending strength at an early age. This situation provides a good advantage of the production of GRC elements. It supports better bonding of glass fibers to the matrix at moderate curing temperatures (20-40°C). Due to this, the formation of cracks decreases. If the curing takes place at the optimum temperature (40-60°C) and the conditions are suitable in terms of humidity (it should be in a humid environment for at least 7 days), its mechanical performance and durability increase.

In the experiments conducted by Ali et al. (1975) on GRC, they applied 2 different curing methods in air and water. Better results have been achieved with air curing. The result is that the elasticity moduli and the stresses at the proportionality limit are higher in water.

Use of waste and recycled materials in GRC production

The use of recycled materials in GRC production has become important for sustainability and economy. For these reasons, existing studies have been conducted and studies have been conducted to investigate the effects of GRCs produced with these recycled materials on the mechanical properties and microstructure. Garcia et al. (2014), conducted a study examining the use and effects of short glass fiber wastes in the waste state in the production of GRC. In this study, the waste glass fibers were collected from aerodynamic fairings on trains, electrical panels, hulls for recreational boats and pultruded GFRP profiles. Glass fibers are separated from other wastes by shredding, grinding and screening to separate them from other wastes. As the proportion of recycled fibers in the GRC increases, the processability of fresh concrete decreases, just like standard manufactured GRCs. If we look at the GRC mechanical properties from the point of view, spherical particles, dust and large splinters affect the mechanical properties in a bad way. However, they showed a positive orientation of 22% in pressure and 16% in bending in optimized fibers In the research conducted by Correia et al. (2011), the wet concrete workability of GRC samples produced using recycled glass fiber fibers showed the same result. But since there was not an increase in mechanical properties, but rather a decrease in the opposite way, recycled glass fibers were recommended to be used in places where more strength was not needed, where the architect's tastes were at the forefront. These two studies have yielded similar results. The second study was conducted in earlier years, and the first study was conducted more recently. In the second study, there is no waste optimization in the recycled aggregate. Similar results were obtained in a recent study before waste optimization was performed. When the study conducted by Ogi et al. (2005) for GRCs produced with recycled GFRP parts was examined, it was found that in fresh concrete behavior, mechanical strength and microstructure similar results were observed with his study (García et al., 2014). GRC can also be produced as a panel and used for different ways and purposes, an example of this is its use in terms of sound insulation, and these sound insulation barriers can be produced from waste materials, as in other GRCs, their acoustic properties were tested using glass-reinforced concrete containing recycled plastic in a study conducted by Pastor et al. (2014b). The manufactured GRC panels have experienced a loss in bending strength from a mechanical point of view, but better results have been encountered in terms of impact and toughness. It has not led to any positive major changes in terms of mechanical properties. A performance increase of between 40% and 50% has been observed in terms of sound insulation. Dec. As seen in the studies, recycled materials have shown that while reducing GRC workability, their mechanical strength can be maintained with optimal values. The results related to microstructure and fresh concrete behavior did not give consistent results due to reasons such as the use of different types of materials. However, different materials add different positive properties. For example, its production in such a way as to serve special applications such as sound insulation. All of these features can be optimized depending on the existing wishes and needs and used in appropriate areas.

ENVIRONMENTAL IMPACT

Environmental Assessment with Life Cycle Analysis

It is possible to make glass fiber from glass fiber polymers that have become waste with the development of different technologies in recent years. This situation is of great importance in terms of sustainability and reducing environmental impacts in the construction sector. In particular, life cycle analysis reveals the potential of GRC for future use. Regarding this, when looking at the recycled GRC compressive strength, separation and tensile strength and drying compressive strength, Deghan et al. (2017) conducted their research using recycled glass fiber reinforcement up to 5% of the gross aggregate weight in their study, only an improvement in separation and tensile strength was observed. When the microstructure was examined with scanning electron microscope, it was observed that glass fibers interact with the pozolanic material. In parallel, Jin et al. (2024), the mechanical properties and life cycle of GRC manufactured with recycled material were examined. The use of waste glass reduces the consumption of natural resources and carbon emissions and has a low environmental footprint. It provides significant savings in terms of energy and water consumption, especially in the production of raw materials. It reduces the environmental burden by having a long service life of concrete and minimizing maintenance needs. Waste glass reinforced GRC is a very advantageous building material both in terms of mechanical performance and environmental sustainability. Life cycle analysis supports that the use of such recycled materials minimizes environmental impacts and increases sustainability in the construction sector. All of these findings appear in front of us as an environmentally friendly, sustainable, durable and economical building material solution of recycled glass fiber reinforced GRC. For these reasons, it shows that it can be used more in the future.

GRC STRUCTURAL APPLICATION

GRC is a very advantageous material in terms of static and architectural aesthetic concerns (Mohamed Ahmed Berrani et al., 2022b). It can be used as building elements, as well as pedestrian bridges, roof elements, floor slabs, or it is used in different places such as telecommunication tower, wind panel wing to respond to special requests (Hassan & Saeed, 2024)(Ferreira & & Branco, 2007). In addition to the superior mechanical properties of the GRCs created by adding glass fiber to the bridge decks, it is known that they contribute positively to the energy absorption capacity and toughness indices (Jan et al., 2022). In order to take a more comprehensive look, Devi et al. (2022) examined the work done by increasing the mechanical properties of glass fibers such as tensile, flexural strength and impact resistance of concrete. GRC shows higher strength and toughness compared to conventional concrete. Glass fibers are used instead of steel reinforcement in some cases and this reduces the weight of the structure and increases the strength of the alkaline environment. GRC offers ease of transportation and installation thanks to its low density. It is also used as a building element in thin and complex shapes. With these features, it is the reason of preference in terms of architecture and engineering. Prefabricated facade elements are used in many areas such as decorative architectural elements, bearing and non-bearing apples, infrastructure structures

GRCs can also be used as the substrate or main layer in electrically conductive concrete technology. Traditionally, the development of heatable conductive concrete, radiation shielding, and smart sensing cementitious materials has been based on the direct addition of conductive fillers into the cement matrix. In contrast, a study conducted by Dehghanpour (2023) has proposed a more efficient approach, which involves covering the surface of non-conductive glass fiber reinforced concrete (GRC) with a thin conductive layer. In the electrically conductive surface coating mixture, single-walled carbon nanotubes (SWCNT) and carbon fibers (CF) were used as conductive additives. Dosages of 0.1%, 0.2%, and 0.3% by weight for SWCNT and 0.2%, 0.4%, 0.6%, 0.8%, and 1.0% by volume for CF were selected. Based on these proportions, a total of 15 different conductive cement coatings were prepared. White Portland cement and fine silica sand were used as binder and filler materials, respectively. The conductive layer, with a thickness of approximately 3 mm, demonstrated good adhesion and integration with the substrate since it was cast simultaneously with the GRC in the same mold. To investigate the electrical, thermal, and microstructural properties of the coatings, resistivity, impedance, heatability (electrothermal), TGA-DTA, and microstructure analyses were performed. Cement-based composite samples containing CF exhibited superior impedance and resistance properties compared to other samples. TGA/DTA analyses revealed that the amount of CF had no significant effect on thermal weight loss. The lowest resistivity values were measured as 20 and 80 Ω·cm for the CF1.0 and CF0.8 samples, respectively. According to the electrothermal test results, when a voltage of 24 V was applied for 1 hour, the temperature increased from 23 °C to 45.5 °C and 28 °C, respectively, with power consumption levels of 750 W/m² and 232 W/m² (Dehghanpour., 2023). The image explaining the summary of this study is given in Fig. 5. Electrically conductive concretes (ECCs) can be used in different areas. ECC is a recommended type of concrete to prevent accumulation of snow and ice in the construction industry (Dehghanpour & Yılmaz., 2020).

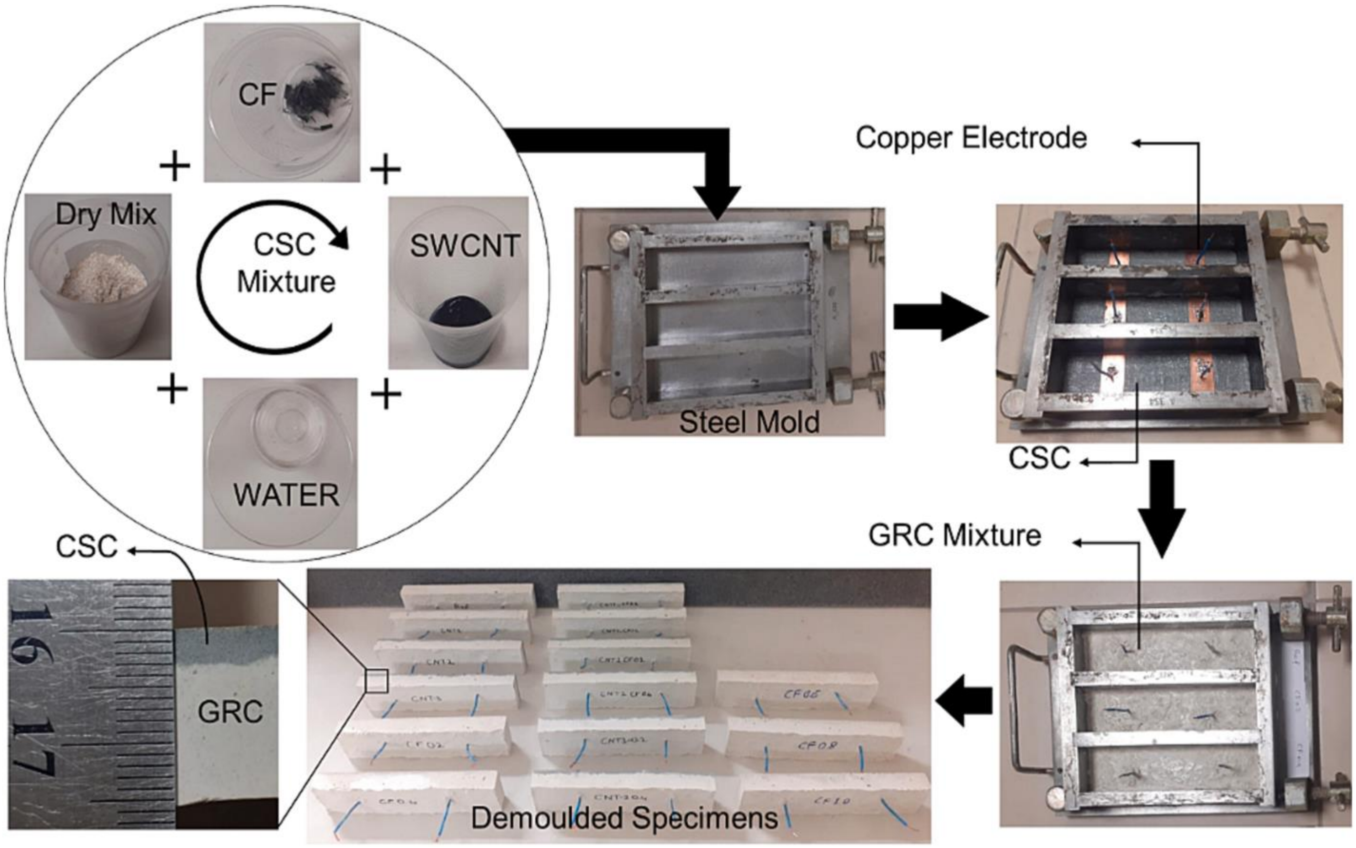

Figure 5. Flow of steps of electrically conductive concrete coating on GRC (Dehghanpour., 2023).

CONCLUSION

The conclusion section should be revised as follows: This study is a review focusing on the effects of glass fibers and various additives on the mechanical and durability properties of glass fiber reinforced concrete (GRC). Glass fiber reinforced concrete (GRC) is a high-performance composite material that offers superior tensile strength, corrosion resistance, and durability compared to conventional concrete. Its lightweight nature and aesthetic flexibility make it particularly suitable for façade cladding, prefabricated components, and industrial applications. The incorporation of pozzolanic additives such as silica fume, metakaolin, and fly ash has been shown to enhance the mechanical properties and long-term durability of GRC by reducing aging-related deterioration. Among these, metakaolin has demonstrated the most significant improvement in mechanical strength. Nanomaterial additives, particularly single-walled carbon nanotubes (SWCNTs), contribute further by enhancing the machinability, corrosion resistance, and interfacial bonding within the matrix. Nano- coatings on glass fibers also improve environmental resistance and increase fiber strength. The performance of GRC is highly dependent on the type, content, and dimensions of the glass fibers used; alkali-resistant glass fibers, in particular, are effective in preventing early-age microcrack formation, thereby improving tensile and flexural strength. Experimental studies confirm that variations in fiber characteristics directly influence the mechanical performance of GRC. Furthermore, the partial replacement of cement with pozzolanic and recycled materials supports both environmental sustainability and mechanical integrity. These advancements have positioned GRC as a preferred material in modern construction practices, especially where lightweight, durable, and sustainable design solutions are required

DECLARATIONS

Data availability

The datasets used and/or analysed during the current study available from the corresponding author on reasonable request.

Competing interests

The author declares no competing interests in this research and publication.

REFERENCES

Ahmad, J., González-Lezcano, R. A., Majdi, A., Ben Kahla, N., Deifalla, A. F., & El-Shorbagy, M. A. (2022). Glass Fibers Reinforced Concrete: Overview on Mechanical, Durability and Microstructure Analysis. *Materials*, *15*(15), 5111. https://doi.org/10.3390/MA15155111

Ali, B., & Qureshi, L. A. (2019). Influence of glass fibers on mechanical and durability performance of concrete with recycled aggregates. *Construction and Building Materials*, *228*, 116783. https://doi.org/10.1016/J.CONBUILDMAT.2019.116783

Ali, M. A., Majumdar, A. J., & Singh, B. (1975). Properties of glass fibre cement - the effect of fibre length and content. *Journal of Materials Science*, *10*(10), 1732–1740. https://doi.org/10.1007/BF00554935/METRICS

Ambroise, J., Dejean, J., Foumbi, J., & Pera, J. (1989). Metakaoline blended cements improve GRC durability and ductility. *Construction and Building Materials*, *3*(2), 73–77. https://doi.org/10.1016/S0950-0618(89)80003-0

Ardahanli, M., Kotan, T., Üniversitesi, E. T., Ve, M., Fakültesi, M., Bölümü, M., Kelimeler, A., & Lif, Ç. (2023). Çelik Tel ve Cam Elyaf Ağları ile Takviye Edilmiş Tabakalı Beton Kompozitlerin Eğilme Dayanımı [Flexural Strength of Layered Concrete Composites Reinforced with Steel Wire and Glass Fiber Mesh]. *Erciyes Üniversitesi Fen Bilimleri Enstitüsü Fen Bilimleri Dergisi*, *39*(2), 163–171. https://dergipark.org.tr/tr/pub/erciyesfen/issue/79712/1254277

Banthia, N., Zanotti, C., & Sappakittipakorn, M. (2014). Sustainable fiber reinforced concrete for repair applications. *Construction and Building Materials*, *67*(PART C), 405–412. https://doi.org/10.1016/J.CONBUILDMAT.2013.12.073

Barhum, R., & Mechtcherine, V. (2012). Effect of short, dispersed glass and carbon fibres on the behaviour of textile-reinforced concrete under tensile loading. *Engineering Fracture Mechanics*, *92*, 56–71. https://doi.org/10.1016/J.ENGFRACMECH.2012.06.001

Barluenga, G., & Hernández-Olivares, F. (2007). Cracking control of concretes modified with short AR-glass fibers at early age. Experimental results on standard concrete and SCC. *Cement and Concrete Research*, *37*(12), 1624–1638. https://doi.org/10.1016/J.CEMCONRES.2007.08.019

Blazy, J., Blazy, R., & Drobiec, Ł. (2022). Glass Fiber Reinforced Concrete as a Durable and Enhanced Material for Structural and Architectural Elements in Smart City—A Review. *Materials 2022, Vol. 15, Page 2754*, *15*(8), 2754. https://doi.org/10.3390/MA15082754

Butler, M., Mechtcherine, V., & Hempel, S. (2010). Durability of textile reinforced concrete made with AR glass fibre: Effect of the matrix composition. *Materials and Structures/Materiaux et Constructions*, *43*(10), 1351–1368. https://doi.org/10.1617/S11527-010-9586-8/METRICS

Çavdar, A. (2012). A study on the effects of high temperature on mechanical properties of fiber reinforced cementitious composites. *Composites Part B: Engineering*, *43*(5), 2452–2463. https://doi.org/10.1016/J.COMPOSITESB.2011.10.005

Cheng, C., He, J., Li, X., & Hong, S. (2024). Flexural behavior of glass fiber reinforced cement incorporating foam. *Journal of Engineered Fibers and Fabrics*, *19*, 15589250241230765. https://doi.org/10.1177/15589250241230765

Cheng, C., He, J., Zhang, J., & Yang, Y. (2019). Study on the time-dependent mechanical properties of glass fiber reinforced cement (GRC) with fly ash or slag. *Construction and Building Materials*, *217*, 128–136. https://doi.org/10.1016/J.CONBUILDMAT.2019.05.063

Correia, J. R., Almeida, N. M., & Figueira, J. R. (2011). Recycling of FRP composites: reusing fine GFRP waste in concrete mixtures. *Journal of Cleaner Production*, *19*(15), 1745–1753. https://doi.org/10.1016/J.JCLEPRO.2011.05.018

Dehghan, A., Peterson, K., & Shvarzman, A. (2017). Recycled glass fiber reinforced polymer additions to Portland cement concrete. *Construction and Building Materials*, *146*, 238–250. https://doi.org/10.1016/J.CONBUILDMAT.2017.04.011

Devi, C., Vijayan, D. S., Nagalingam, R., & Arvindan, S. (2022). A review of the implementations of glass fiber in concrete technology. *Materials Today: Proceedings*, *62*, 2010–2015. https://doi.org/10.1016/J.MATPR.2022.02.293

Enfedaque, A., Cendón, D., Gálvez, F., & Sánchez-Gálvez, V. (2010). Analysis of glass fiber reinforced cement (GRC) fracture surfaces. *Construction and Building Materials*, *24*(7), 1302–1308. https://doi.org/10.1016/J.CONBUILDMAT.2009.12.005

Enfedaque, A., Cendón, D., Gálvez, F., & Sánchez-Gálvez, V. (2011). Failure and impact behavior of facade panels made of glass fiber reinforced cement (GRC). *Engineering Failure Analysis*, *18*(7), 1652–1663. https://doi.org/10.1016/J.ENGFAILANAL.2011.01.004

Enfedaque, A., Gálvez, J. C., & Suárez, F. (2015). Analysis of fracture tests of glass fibre reinforced cement (GRC) using digital image correlation. *Construction and Building Materials*, *75*, 472–487. https://doi.org/10.1016/J.CONBUILDMAT.2014.11.031

Enfedaque, A., Paradela, L. S., & Sánchez-Gálvez, V. (2012). An alternative methodology to predict aging effects on the mechanical properties of glass fiber reinforced cements (GRC). *Construction and Building Materials*, *27*(1), 425–431. https://doi.org/10.1016/J.CONBUILDMAT.2011.07.025

Ferreira, J. G., & Branco, F. A. (2007). Structural application of GRC in telecommunication towers. *Construction and Building Materials*, *21*(1), 19–28. https://doi.org/10.1016/J.CONBUILDMAT.2005.08.003

Ferreira, J. P. J. G., & Branco, F. A. B. (2007). The use of glass fiber-reinforced concrete as a structural material. *Experimental Techniques*, *31*(3), 64. https://doi.org/10.1111/J.1747-1567.2007.00153.X

Gao, S. L., Mäder, E., & Plonka, R. (2007). Nanostructured coatings of glass fibers: Improvement of alkali resistance and mechanical properties. *Acta Materialia*, *55*(3), 1043–1052. https://doi.org/10.1016/J.ACTAMAT.2006.09.020

Gao, S. L., Mäder, E., & Plonka, R. (2008). Nanocomposite coatings for healing surface defects of glass fibers and improving interfacial adhesion. *Composites Science and Technology*, *68*(14), 2892–2901. https://doi.org/10.1016/J.COMPSCITECH.2007.10.009

García, D., Vegas, I., & Cacho, I. (2014). Mechanical recycling of GFRP waste as short-fiber reinforcements in microconcrete. *Construction and Building Materials*, *64*, 293–300. https://doi.org/10.1016/J.CONBUILDMAT.2014.02.068

Genovés, V., Gosálbez, J., Miralles, R., Bonilla, M., & Payá, J. (2015). Ultrasonic characterization of GRC with high percentage of fly ash substitution. *Ultrasonics*, *60*, 88–95. https://doi.org/10.1016/J.ULTRAS.2015.02.016

Georgali, B., & Tsakiridis, P. E. (2005). Microstructure of fire-damaged concrete. A case study. *Cement and Concrete Composites*, *27*(2), 255–259. https://doi.org/10.1016/j.cemconcomp.2004.02.022

Güneyisi, E., Atewi, Y. R., & Hasan, M. F. (2019). Fresh and rheological properties of glass fiber reinforced self-compacting concrete with nanosilica and fly ash blended. *Construction and Building Materials*, *211*, 349–362. https://doi.org/10.1016/J.CONBUILDMAT.2019.03.087

Gutierrez Melgarejo, R. C. (2019). Mitigation of aging of glass fiber reinforced cement (GRC) using pozzolan and acrylic resin additions. *2019 Congreso Internacional de Innovacion y Tendencias En Ingenieria, CONIITI 2019 - Conference Proceedings*. https://doi.org/10.1109/CONIITI48476.2019.8960772

Hassan, H. Z., & Saeed, N. M. (2024). Fiber reinforced concrete: a state of the art. *Discover Materials 2024 4:1*, *4*(1), 1–44. https://doi.org/10.1007/S43939-024-00171-W

İskender, M., Karasu, B. ; M., & Karasu, B. (2018). Glass Fibre Reinforced Concrete (GFRC). *El-Cezerî Journal of Science and Engineering*, *5*(1), 136–162. www.dergipark.gov.tr

Jan, A., Pu, Z., Khan, K. A., Ahmad, I., & Khan, I. (2022). Effect of Glass Fibers on the Mechanical Behavior as Well as Energy Absorption Capacity and Toughness Indices of Concrete Bridge Decks. *Silicon*, *14*(5), 2283–2297. https://doi.org/10.1007/S12633-021-01026-2/METRICS

Jiao, D., Shi, C., Yuan, Q., Zhu, D., & De Schutter, G. (2019). Effects of rotational shearing on rheological behavior of fresh mortar with short glass fiber. *Construction and Building Materials*, *203*, 314–321. https://doi.org/10.1016/J.CONBUILDMAT.2019.01.133

Jin, Z., Liang, K., Liu, C., Yang, G., Cui, K., & Mao, S. (2024). Mechanical properties and life cycle assessment (LCA) of waste glass reinforced concrete. *Journal of Building Engineering*, *96*, 110643. https://doi.org/10.1016/J.JOBE.2024.110643

Kizilkanat, A. B., Kabay, N., Akyüncü, V., Chowdhury, S., & Akça, A. H. (2015a). Mechanical properties and fracture behavior of basalt and glass fiber reinforced concrete: An experimental study. *Construction and Building Materials*, *100*, 218–224. https://doi.org/10.1016/J.CONBUILDMAT.2015.10.006

Kizilkanat, A. B., Kabay, N., Akyüncü, V., Chowdhury, S., & Akça, A. H. (2015b). Mechanical properties and fracture behavior of basalt and glass fiber reinforced concrete: An experimental study. *Construction and Building Materials*, *100*, 218–224. https://doi.org/10.1016/J.CONBUILDMAT.2015.10.006

Lalinde, L. F., Mellado, A., Borrachero, M. V., Monzó, J., & Payá, J. (2022). Durability of Glass Fiber Reinforced Cement (GRC) Containing a High Proportion of Pozzolans. *Applied Sciences 2022, Vol. 12, Page 3696*, *12*(7), 3696. https://doi.org/10.3390/APP12073696

Lu, J., Liu, J., Yang, H., Gao, J., Wan, X., & Zhang, J. (2022). Influence of curing temperatures on the performances of fiber-reinforced concrete. *Construction and Building Materials*, *339*, 127640. https://doi.org/10.1016/J.CONBUILDMAT.2022.127640

Madhkhan, M., & Katirai, R. (2019a). Effect of pozzolanic materials on mechanical properties and aging of glass fiber reinforced concrete. *Construction and Building Materials*, *225*, 146–158. https://doi.org/10.1016/J.CONBUILDMAT.2019.07.128

Madhkhan, M., & Katirai, R. (2019b). Effect of pozzolanic materials on mechanical properties and aging of glass fiber reinforced concrete. *Construction and Building Materials*, *225*, 146–158. https://doi.org/10.1016/J.CONBUILDMAT.2019.07.128

Madhkhan, M., & Katirai, R. (2019c). Effect of pozzolanic materials on mechanical properties and aging of glass fiber reinforced concrete. *Construction and Building Materials*, *225*, 146–158. https://doi.org/10.1016/J.CONBUILDMAT.2019.07.128

Maraşlı, M., Guntepe, S., Ozdal, V., Kohen, B., Deghanpour, H., & Subaşı, S. (2023). *Development of Maturity Measurement Method and Device in Glass Fiber Reinforced Concrete (GRC)*. https://www.researchgate.net/publication/372413234_Development_of_Maturity_Measurement_Method_and_Device_in_Glass_Fiber_Reinforced_Concrete_GRC

Marasli, M., Subasi, S., & Dehghanpour, H. (2022). Development of a maturity method for GFRC shell concretes with different fiber ratios. *European Journal of Environmental and Civil Engineering*, *26*(16), 8458–8476. https://doi.org/10.1080/19648189.2022.2028190;CTYPE:STRING:JOURNAL

Mohamed Ahmed Berrani, A., Çağlar, H., Çağlar, A. (2022a). Cam Elyaf Takviyeli Precast Beton Cephe Panellerinin Uygulanişi (Ankara Örneklemi) [Application of Glass Fiber Reinforced Precast Concrete Facade Panels (Ankara Sample)]. *Journal of Sustainable Engineering Applications and Technological Developments*, *5*(2), 177–187. https://doi.org/10.51764/SMUTGD.1122647

Muna, M. A., & Eman, K., J. (2012). Mechanical Properties of Glass Fiber Reinforced Concrete Mechanical. *Al-Rafadain Eng. J.*, 128–135.

Murthada Ali, C., Hakan Arslan, M., Altın, M., Sözcükler Yangın, A., (2019). Cam Lif Takviyeli Betonun Yangın Dayanımlarının Çeşitli Parametreler Açısından İrdelenmesi [Investigation of Fire Resistance of Fiber-Reinforced Concrete in Terms of Various Parameters]. *Doğal Afetler ve Çevre Dergisi*, *5*(2), 198–213. https://doi.org/10.21324/DACD.458094

Ogi, K., Shinoda, T., & Mizui, M. (2005). Strength in concrete reinforced with recycled CFRP pieces. *Composites Part A: Applied Science and Manufacturing*, *36*(7), 893–902. https://doi.org/10.1016/J.COMPOSITESA.2004.12.009

Orlowsky, J., Raupach, M., Cuypers, H., & Wastiels, J. (2005). Durability modelling of glass fibre reinforcement in cementitious environment. *Materials and Structures 2004 38:2*, *38*(2), 155–162. https://doi.org/10.1007/BF02479340

OTTO, W. H. (1955). Relationship of Tensile Strength of Glass Fibers to Diameter. *Journal of the American Ceramic Society*, *38*(3), 122–125. https://doi.org/10.1111/J.1151-2916.1955.TB14588.X

Pastor, J. M., García, L. D., Quintana, S., & Peña, J. (2014a). Glass reinforced concrete panels containing recycled tyres: Evaluation of the acoustic properties of for their use as sound barriers. *Construction and Building Materials*, *54*, 541–549. https://doi.org/10.1016/J.CONBUILDMAT.2013.12.040

Pastor, J. M., García, L. D., Quintana, S., & Peña, J. (2014b). Glass reinforced concrete panels containing recycled tyres: Evaluation of the acoustic properties of for their use as sound barriers. *Construction and Building Materials*, *54*, 541–549. https://doi.org/10.1016/J.CONBUILDMAT.2013.12.040

Purnell, P., Short, N. R., & Page, C. L. (2001a). A static fatigue model for the durability of glass fibre reinforced cement. *Journal of Materials Science*, *36*(22), 5385–5390. https://doi.org/10.1023/A:1012496625210/METRICS

Purnell, P., Short, N. R., & Page, C. L. (2001b). Super-critical carbonation of glass-fibre reinforced cement. Part 1: mechanical testing and chemical analysis. *Composites Part A: Applied Science and Manufacturing*, *32*(12), 1777–1787. https://doi.org/10.1016/S1359-835X(01)00019-7

Saribiyik, M., Piskin, A., & Saribiyik, A. (2013). The effects of waste glass powder usage on polymer concrete properties. *Construction and Building Materials*, *47*, 840–844. https://doi.org/10.1016/J.CONBUILDMAT.2013.05.023

Seneviratne, A. M. G., Short, N. R., Purnell, P., & Page, C. L. (2002). Preliminary investigations of the dimensional stability of super-critically carbonated glass fibre reinforced cement. *Cement and Concrete Research*, *32*(10), 1639–1644. https://doi.org/10.1016/S0008-8846(02)00837-2

Subasi, S., Dehghanpour, H., & Marasli, M. (2022). Production and Characterization of GRC-SWCNT Composites for Shell Elements. *Materials Science*, *28*(4), 423–433. https://doi.org/10.5755/J02.MS.29008

Toklu, K., Emre Avşar, Y., Timur Cihan, M., & LastNameBıçakçı, E. (2022). Cam Lifi Uzunluğu ve Oranının Çimento Harçlarının Mekanik Özelliklerine Etkisi [Effect of Glass Fiber Length and Ratio on Mechanical Properties of Cement Mortars]. *International Journal of Engineering Research and Development*, *14*(1), 95–102. https://doi.org/10.29137/UMAGD.955365

Xiaochun, Q., Xiaoming, L., & Xiaopei, C. (2017). The applicability of alkaline-resistant glass fiber in cement mortar of road pavement: Corrosion mechanism and performance analysis. *International Journal of Pavement Research and Technology*, *10*(6), 536–544. https://doi.org/10.1016/J.IJPRT.2017.06.003

Yang, W., Huang, Y., Li, C., Tang, Z., Quan, W., Xiong, X., He, J., & Wu, W. (2024). Damage prediction and long-term cost performance analysis of glass fiber recycled concrete under freeze-thaw cycles. *Case Studies in Construction Materials*, *21*, e03795. https://doi.org/10.1016/J.CSCM.2024.E03795

Yildiz S, & Bölükbaş Y. (2010). Cam Elyaf Katkısının Betonun Basınç ve Çekme Dayanımı Üzerindeki Etkisi [Effect of Glass Fiber Additive on Compressive and Tensile Strength of Concrete]. *Politeknik Dergisi*, *13*(3), 239–243. https://dergipark.org.tr/tr/download/article-file/386022

Yildiz S, Bölükbaş Y, & Keleştemur O. (2010). Cam Elyaf Katkısının Betonun Basınç ve Çekme Dayanımı Üzerindeki Etkisi [Effect of Glass Fiber Additive on Compressive and Tensile Strength of Concrete]. *I Journal of Polytechnic*, *13*(3), 239–243. https://dergipark.org.tr/tr/download/article-file/386022

Yıldız, P. (2022). Cam elyaf takviyeli beton panel-doğrama birleşimi su geçirimsizlik detay tasarım önerileri [Detailed design recommendations for water impermeability of glass fiber reinforced concrete panel-joinery joints]. Lisansüstü Eğitim Enstitüsü. http://hdl.handle.net/11527/24052

Yildiz, S., & Keleştemur, M. H. (2000). Cam lif katkısının beton dayanımına etkisi [Effect of glass fiber additive on concrete strength]. *Fırat Üniversitesi Fen ve Mühendislik Bilimleri Dergisi* , *12*(1), 373–381. /tr/yayin/detay/33867

Yilmaz, V., & Glasser, F. P. (1991). Reaction of alkali-resistant glass fibres with cement. Part 2. Durability in cement matrices conditioned with silica fume. *GLASS TECHNOLOGY*, *32*.

Yuan, Z., & Jia, Y. (2021). Mechanical properties and microstructure of glass fiber and polypropylene fiber reinforced concrete: An experimental study. *Construction and Building Materials*, *266*, 121048. https://doi.org/10.1016/J.CONBUILDMAT.2020.121048

Yurdakul, A., Günkaya, G., Kavas, T., Dölekçekiç, E., & Karasu, B. (2014). Electron Microscopy Observations on Glass Fiber Reinforced Concrete (GFRC) Materials. *AKU J. Sci. Eng*, *14*, 185–191.

Zhen, H., Xiong, Z., Song, Y., Li, L., Qiu, Y., Zou, X., Chen, B., Chen, D., Liu, F., & Ji, Y. (2024). Early mechanical performance of glass fibre-reinforced manufactured sand concrete. *Journal of Building Engineering*, *83*, 108440. https://doi.org/10.1016/J.JOBE.2024.108440