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Research Article

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The ductility performance of concrete using glass fiber mesh in beam specimens

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Abstract: It is known that concrete with high ductility reduces fatalities because it absorbs more energy during an earthquake. The aim of this study is to increase the ductility of concrete by using glass fiber mesh (GFM) left over from the use of plaster in structures and to support sustainability by reusing waste materials in concrete. Another aim is to contribute to the economy by using waste fibers instead of expensive fibers such as carbon and polypropylene in concrete. Two types of concrete were used: class C25 concrete and self-compacting concrete. The specified number of GFM materials was cut into 3 cm wide pieces and placed in 10 cm × 10 cm × 50 cm concrete beam specimens in varying numbers. It was found that the flexural values of the obtained specimens gave slightly better results than the prepared reference specimen. In addition, the increasing stress zones in the beams were visualized using the ANSYS software.

Keywords: fiber, sustainable building materials, waste and recyclable materials, concrete, beam

1 Introduction

The main disadvantage of concrete is that concrete has low tensile strength and is less resistant to deformation [1,2] Different types of fibers are used to improve the flexural strength, fatigue resistance, and impact resistance of cementitious composites [3].

The application of rubberized concrete in earthquake zones is of great importance. The concrete beams incorporating waste rubber exhibited a 23.47% enhancement in ductility when contrasted with the control beam [4]. Over the past 10 years, efforts have been made to introduce ductility to concrete, with fiber-reinforced concrete being a notable approach [5]. To obtain a ductile beam, it depends on some parameters of the concrete class or fiber additions. Furthermore, as the quantity of jute fabrics was raised, the ductility of the beam specimens correspondingly increased [6]. Textiles and clothing are among our most important necessities of life. The textile and fashion industries have been forced to develop and put into practice ecologically friendly waste management and disposal techniques as a result of the growing environmental issues connected to the massive amounts of textile waste that are dumped in landfills. The textile sector is recognized as the second most significant source of industrial pollution. It contributes to 10% of worldwide carbon emissions and 20% of global wastewater [7]. Synthetic petroleum-based textiles in particular pose a major threat to environmental pollution. Unfortunately, their use and therefore production has increased in recent years [8]. Numerous components from non-biodegradable building waste will remain in the environment for hundreds or even thousands of years, contributing to environmental problems [9,10]. It is important to recycle plastic-containing waste or use it as a fiber in concrete.

It was found that concrete with textile or synthetic fibers has a higher elongation at break than PC concrete [11,12]. Another important condition is to reduce the weight of engineering structures as much as possible [13,14]. This type of building material is lighter than steel reinforcements and does not have disadvantages such as corrosion. Concrete is a kind of material that it is reinforced with fibers to increase its ductility [15–18]. Furthermore, the fibers increase the ductility of the concrete and contribute positively to its waterproofness [19]. In a study, it was shown that by reusing waste rope fibers in concrete, the compressive strength of concrete increased by up to 22% and the flexural strength increased by 4.3% [20]. Figure 1 shows the share of textiles consumed worldwide in 2021. More and more synthetic textiles are being used. In this case, there is an increasing.

Fiber-reinforced polymers (FRP) are used in many industries because of their excellent mechanical properties and durability. This means that more and more FRP waste has to be processed in production. Conventional FRP composites are usually thermoset and non-biodegradable and

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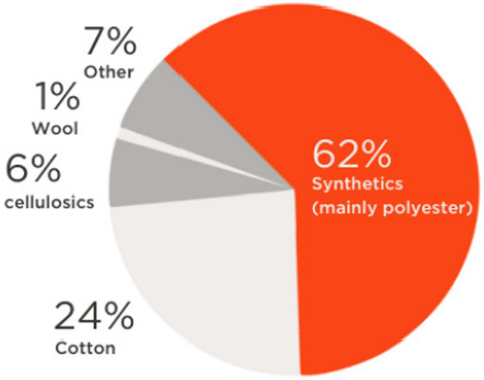


Figure 1: Rates of textiles consumed in the world in 2021 [21].

pose a significant risk to the environment if they are not properly disposed of at the end of their life [13]. For this reason, the waste from FRP composites should be used in concrete or alternative recyclable materials should be used. Carbon fibers used in fabric-reinforced concrete matrix (FRCM) systems have been used [22–25]. In lieu of these products derived from petroleum, textile waste was employed in the samples of the beams. The use of FRP created a new composite system known as FRCM or textile-reinforced mortar [26–32].

Experimental and theoretical research on FRCM composites is still very limited compared to the number of studies on FRP systems [33–35]. The addition of various polypropylene fabrics to the concrete significantly increased the freeze–thaw resistance [36]. Polymer fabric-reinforced cemented matrix concretes increased their resistance to cracking by over 30% [37]. The flexural strength of basalt textile-reinforced concrete specimens was noted to enhance as the number of textile layers increased [38].

The addition of fiber to concrete contributes to an improvement in energy absorption capacity as well as durability, increasing the strength of the structure and its resistance to fire [39]. The drying shrinkage and mechanical and rheological properties [40] of concrete have undergone enhancement by the use of natural fibers [41–44]. In particular, short fibers were used in order not to adversely affect the rheological properties of concrete [45]. The production of synthetic fibers requires high energy consumption and will lead to significant environmental issues. Environmental concerns and industrial pollution have driven the engineering industry to seek fiber alternatives beyond synthetic and steel fibers. Readily available, biodegradable, cost-effective, and non-toxic natural fibers are seen as the best possible alternatives [46]. Adding natural fibers to concrete can increase impact resistance, while excessive fiber addition can lead to the deterioration of material properties [47]. As the workability of concrete decreases due to the use of fibers, problems arise with the concrete mix and its placement in the mold. The use of self-compacting concrete (SCC) avoids such problems [48–51].

It is well known that the remaining parts of GFM used in construction pollute the environment as waste. For this reason, in this study, by using these GFM in concrete, it is possible to increase the flexural strength of concrete partially and to contribute to environmental cleaning by evaluating this waste material. Since the GFM was in fabric form, the beam was placed inside the samples to form a layer during concrete pouring. It was thought that it would increase the adhesion due to its mesh structure and increase the ductility because it acts as a fiber.

2 Experimental details

2.1 Specimen design

The dimensions of the manufactured beam samples were 10 cm × 10 cm × 50 cm. The GFM used in the manufactured specimens was attached in two stages. In the first specimens, the fibers were placed on the 1/3 level of the concrete beam, and in the others on both the 1/3 and 2/3 levels. Additionally, two fibers were used in each layer of the specified samples, while three fibers were used in each layer of the other samples. Each waste GFM was cut 3 cm wide. The fibers were inserted straight and diagonally into the test specimens (Figure 2). The fibers were positioned within the plane adjacent to the lower region, which constitutes the tensile area of the specimens. Figure 3 illustrates the experimental study's phases in a schematic manner.

2.2 Materials

In plaster mesh, produced according to DIN ISO 13934-1, the tensile strength should be at least (N/50) and under standard conditions, it should be 1,600 N for warp and 1,900 N for weft. CEM I 42.5R Portland cement is used. A superplasticizer, a product of the company SIKA, was used for the production of the SCC.

2.3 Test methods

Flexural tests were performed in line with TS EN 12390-5 standards, and Figure 4 depicts the results of the

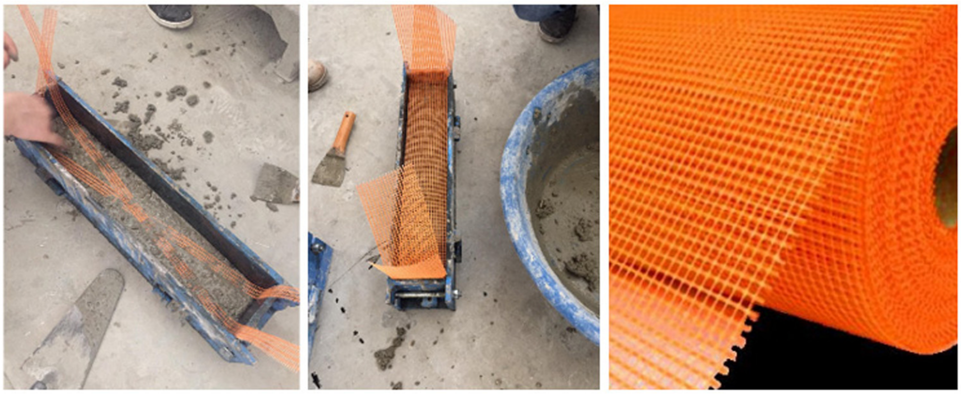


Figure 2: Placing GFM diagonally or straight into concrete beams.

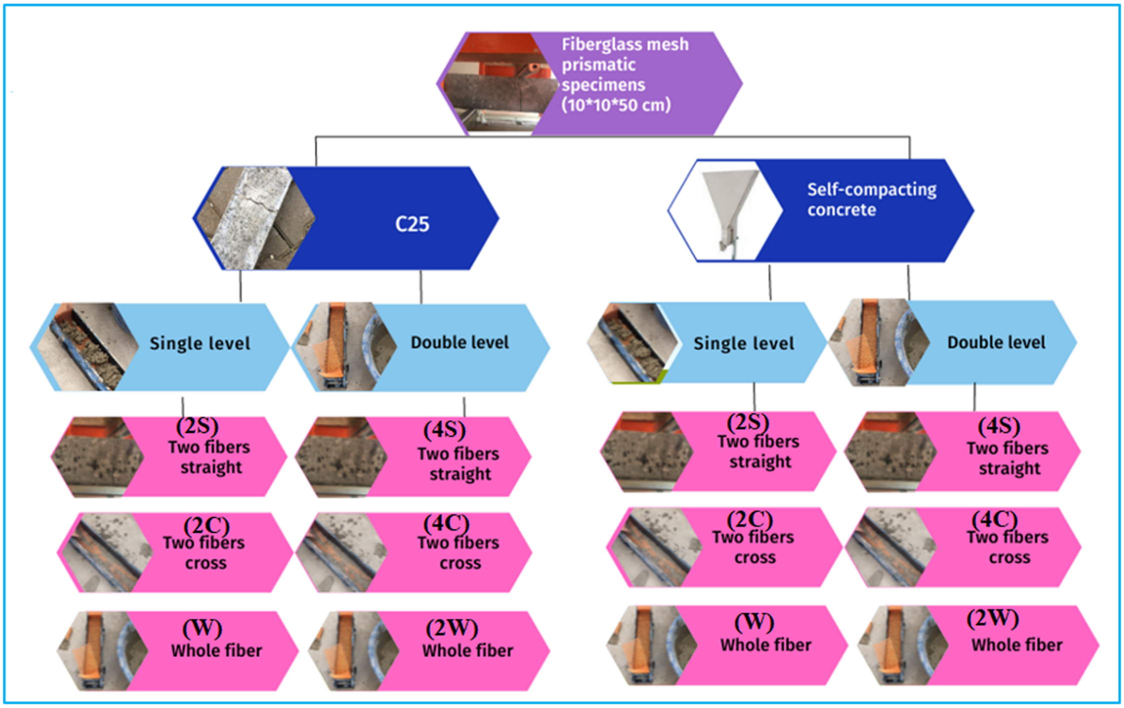


Figure 3: Levels of experimental study.

Figure 4: Flexural test on the sample.

experimental investigation. Testing for durability in sulfated waters was done in accordance with ASTM C1012 guidelines.

3 Results and discussion

3.1 Flexural test

As can be seen in Figure 5, while the fibers in C25 concrete specimens outperformed the reference specimen, the flexural

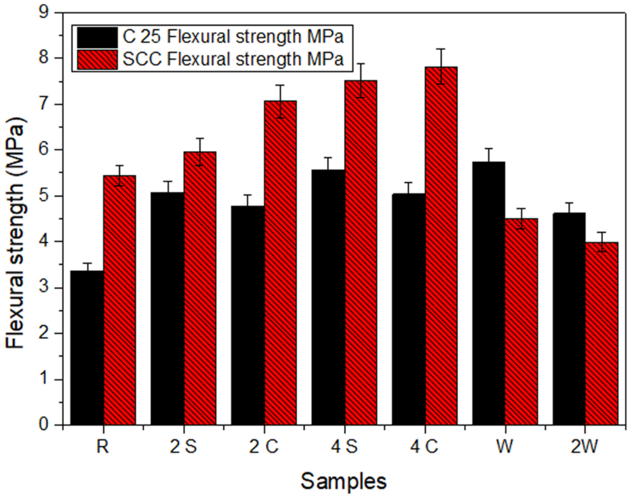


Figure 5: 28-Day flexural strength tests of GFM in C25 and SCC concrete specimens.

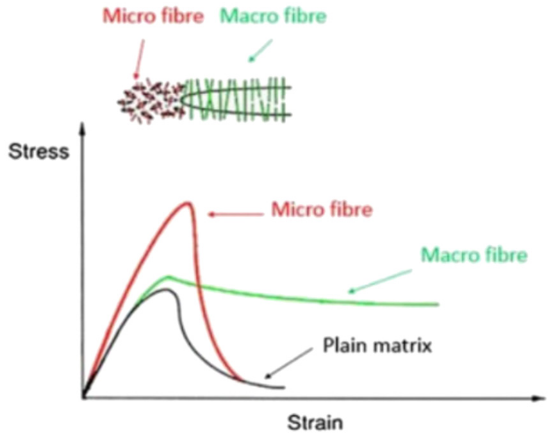
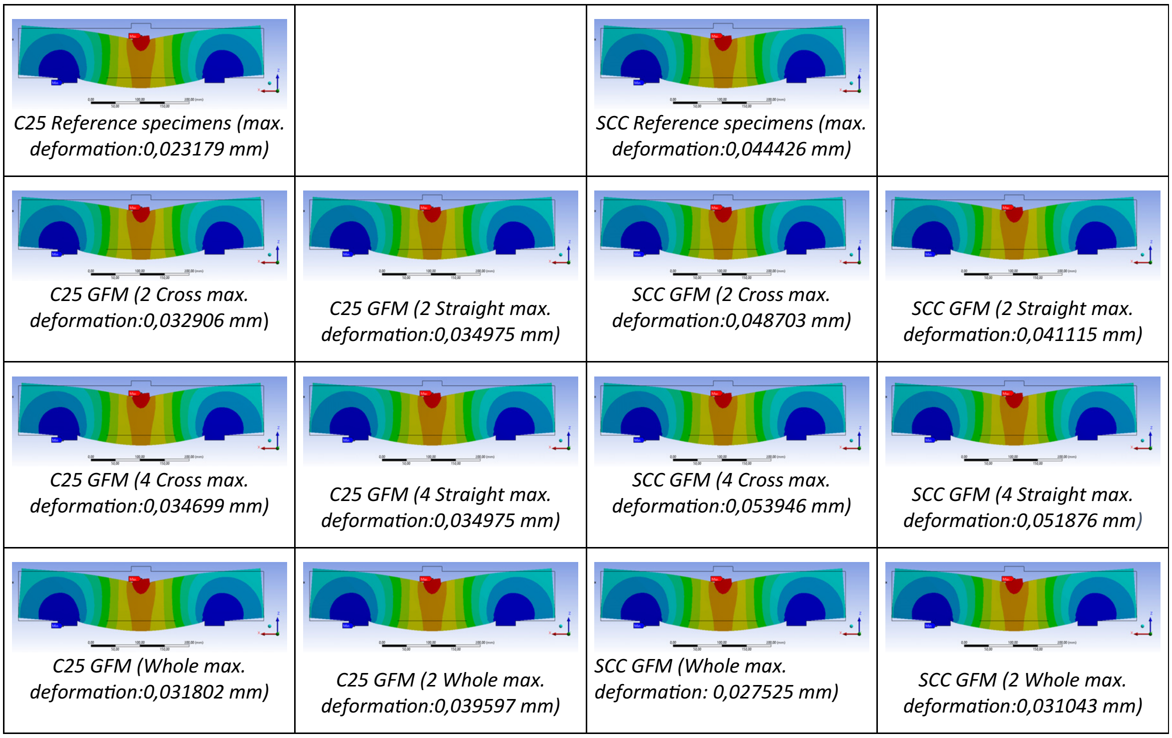


Figure 6: Mechanism of different sizes of fiber reinforcement [55].

strength values obtained from SCC produced slightly better results. In both forms of concrete, it is conceivable to say that the flexural strength values produce better results as the number of fibers grows. It is clear from Figure 5 that fibers in the cross position perform worse than fibers in the straight position.

The fracture mode of the beam switched from brittle fracture to ductile fracture as the number of fibers increased. Analysis of the cracking pattern revealed that the ductile direction of breaking was increased in fiberglass beams. Since the GFM helps to avoid cracks, the presence of fiber reduces the shear stress in the beams.

The flexural strength values of the GFM-containing C25 samples were lower than the SCC samples. The reason for this is thought to change the position of the fibers in the mold with the vibration applied to the C25 concrete. SCC had the best value for flexural strength; the sample with 4 fibers measured 7.82 MPa, compared to 5.44 MPa for the reference sample. The flexural strengths of samples containing 4 fibers have shown an increase of approximately 43% compared to the reference sample. The fiber-containing


C25 Reference specimens (max. deformation:0,023179 mm)

SCC Reference specimens (max. deformation:0,044426 mm)

C25 GFM (2 Cross max. deformation:0,032906 mm)

C25 GFM (2 Straight max. deformation:0,034975 mm)

SCC GFM (2 Cross max. deformation:0,048703 mm)

SCC GFM (2 Straight max. deformation:0,041115 mm)

C25 GFM (4 Cross max. deformation:0,034699 mm)

C25 GFM (4 Straight max. deformation:0,034975 mm)

SCC GFM (4 Cross max. deformation:0,053946 mm)

SCC GFM (4 Straight max. deformation:0,051876 mm)

C25 GFM (Whole max. deformation:0,031802 mm)

C25 GFM (2 Whole max. deformation:0,039597 mm)

SCC GFM (Whole max. deformation: 0,027525 mm)

SCC GFM (2 Whole max. deformation:0,031043 mm)

Figure 7: GFM 28-day specimens FEM analysis (2C–4C: cross position, 2D–4D: straight position, and W: whole).

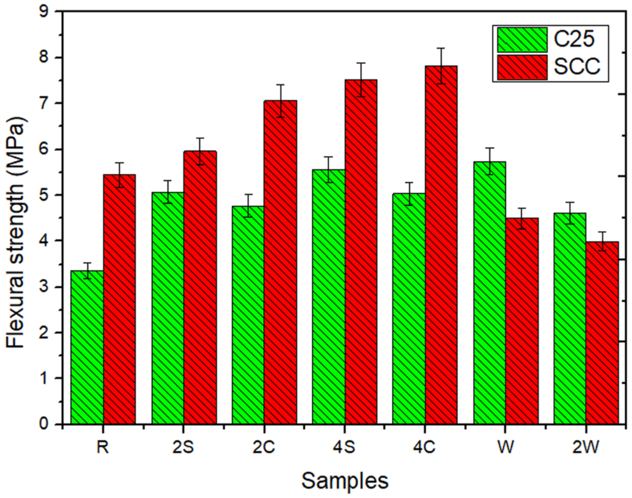


Figure 8: 90-Day flexural strength tests of GFM in C25 and SCC concrete specimens.

beams in this instance were roughly 1.5 times more numerous than the reference sample. The fibers placed in the cross position gave lower values in C25 concretes than those placed in the straight position.

In previous studies, fibers of short lengths were directly added to the mixture mortar in specific proportions without being placed throughout the specimen, and their toughness and ductility were examined. During an earthquake, concrete's brittle fracture poses a serious risk to human life. For this reason in our investigation, GFM is used along the beam specimen to try to offer ductile fracture by minimizing sudden fracture and to boost the load-absorbing capacity of the concrete against flexural forces. Previous research has shown that fiber utilization promotes ductility, and Figure 6 even shows that long fibers can withstand more stress than short fibers [52–54].

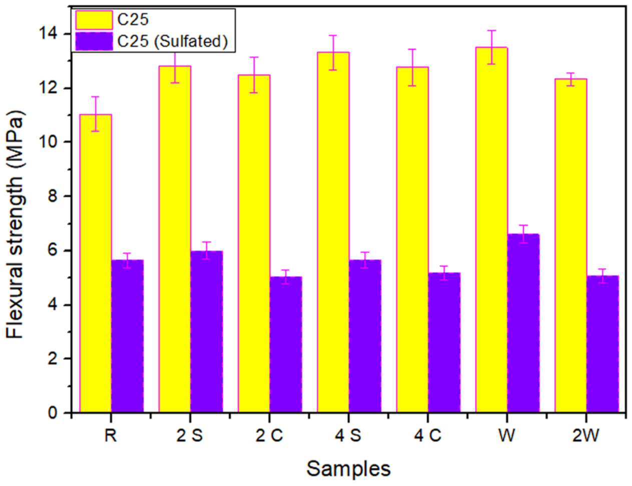


Figure 9: C25 specimens kept in sulfated water for 90 days.

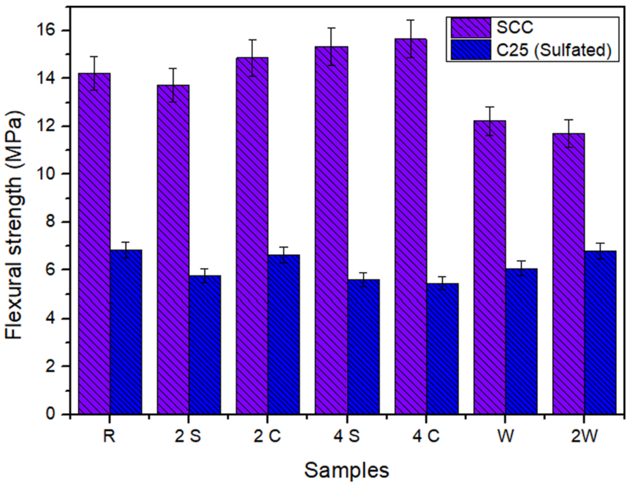


Figure 10: SCC specimens kept in sulfated water for 90 days.

Figure 7 depicts the deformation zones discovered using the finite element method (FEM) analysis of concrete samples with GFM that are 28 days old. It can be shown that the C25 and SCC samples have superior deformation capacities than the reference samples. In a similar study, beams using steel-polypropylene fibers in short form exhibited a 17% increase in cracking load compared to concrete beams without fibers [56].

3.2 90-Day flexural test

As shown in Figure 8, the results are consistent and the best flexural strength values were obtained from SCC specimens placed in a flat position. In another study, it improves

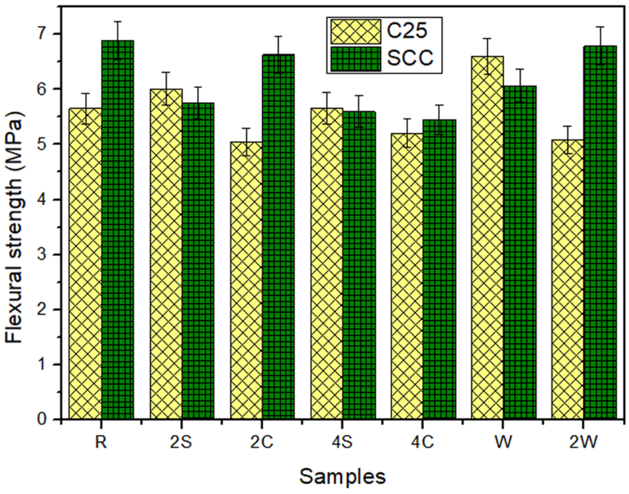


Figure 11: Flexural strength values for 90 days in sulfated water.

quality control by reducing or eliminating traditional reinforcement and simplifying reinforcement details and placement. Combining fiber and SCC also supports sustainability [57].

3.3 Durability tests in sulfated waters

In Figures 9 and 10, the flexural strength of specimens immersed in a 5% Na_2SO_4 solution for 3 months exhibited a notable decrease when compared to the specimens stored in water for 90 days. In addition, since the flexural values of the reference specimens and the fibrous specimens were very close to each other, it was observed that the fibers did not have a positive effect in sulfated environments. In this case, the fiberglass mesh is considered to dissolve in sulfated water. Similar strength values were seen in both groups held in sulfated water, even though the water strength of the SCC samples rose slightly over time compared to the C25 concrete samples.

In Figure 11, in C25 and SCCs immersed in sulfate waters, the straight or cross position of the fibers did not make much difference in the flexural values. Because it supports the idea that the fibers melt and lose their effectiveness in both groups.

4 Conclusion

- Among the 28-day C25 concrete specimens, they have the highest flexural strength value of 5.74 MPa, they are 4-fiber, that is, 2-level and flat-positioned specimens with 2 fibers at each level.
- Within the set of specimens utilizing 28-day SCC, the specimen with the highest flexural strength value was achieved by the configuration with 4 fibers (2 fibers per level) in a cross position, measuring 7.82 MPa.
- Among the specimens using 90-day C25 concrete, the highest flexural strength value is 13.50 MPa, and 4-fibered (2 fiber-2 level) and straight-position specimens.
- Within the category of specimens employing 90-day SCC, the specimen featuring the highest flexural strength measurement was attained by the setup with 4 fibers (2 fibers per level) in a cross position, recording a value of 15.64 MPa.
- Among the C25 concrete specimens kept in sulfate water for 90 days, the highest flexural strength value is 7.15 MPa with whole (2 level) specimen.
- Flexural strength values of all SCC specimens kept in sulfated water for 90 days are lower than the reference specimen.
- The deflection capacity in the beams increases in direct proportion to the number of fibers, the fibers induce ductile fracture even in straight or cross positions, and the reference samples experience the most brittle fracture.

It is understood that SCC specimens are more successful. Since no vibration is applied to the SCC, it is thought that the fibers maintain their position and fulfill their functions, while the fiberglass mesh provides better adhesion to the concrete thanks to its mesh structure.

The flexural strength values of the fibrous specimens exposed to sulfated water exhibited significant reductions in both the C25 concrete category and the SCC category. Both the SCC and C25 concrete classes had significant declines in flexural strength values as a result of the fibrous specimens' exposure to sulfated waters. According to the findings of this study, using waste GFM in concrete will contribute positively effect to the environment while increasing the flexural strength and ductile fracture of the beams in both SCC and C25 concrete samples. In addition, since it is plastic based, it does not pose a corrosion hazard in concrete.

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