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Research paper

FLEXURAL STRENGTH CAPACITY OF THE CONCRETE BEAMS PRODUCED USING DIFFERENT CONCRETE VARIABLES

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Abstract

Flexural strength capacity of the concrete beams depends on different variables such as compressive strength of the concrete, type of the reinforcement used, amount of the reinforcement and cross section of the beam. The flexural strength is expressed as Modulus of Rupture, and it is determined according to ASTM C 293 (center-point-loading). This research is dedicated to investigation of the flexural strength capacity of the concrete beams fabricated using different type of concrete mixtures and different type of reinforcement. The tests presented here were conducted on concrete beams having square cross sections 6 x 6in with 5 ft in length (15cm x 15cm x 1.52m) at Kennesaw State University. Two different types of reinforcement were investigated: type #4 (13mm) rebar and Greenbar 2x1/2in Fiberglass #4 (13mm) rebar along with two different concrete mixture types. Type III cement was used in order to achieve high early strength, and beams were tested to failure when concrete reached prescribed value of 4000 psi (27.6 MPa). In this experimental program load-deflection relationship, load capacity and ductility were the main parameters which were investigated.

Key words: *Flexural Strength Capacity, Ductility, Load-Deflection relationship*

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1. INTRODUCTION

Flexural strength is a fundamental parameter in evaluating the performance of reinforced concrete members subjected to bending. It is influenced by multiple factors, including the compressive strength of the concrete, the type and amount of reinforcement, and the geometry of the cross section. The flexural strength of concrete beams is commonly expressed as the Modulus of Rupture and is typically determined through standardized testing procedures such as ASTM C293, which utilizes a center-point loading method.

In recent years, there has been growing interest in exploring alternative reinforcement materials and concrete mixtures to enhance structural performance and durability. Among these alternatives fiberglass reinforcement—have emerged as a promising substitute for conventional steel reinforcement, particularly in aggressive environments where corrosion resistance is critical. According to Ahmed Lamine investigation [1] the gain in terms of concrete strength by reinforcement with fiberglass was significant and around 37% and decrease in the radial deformation was observed. Xiangije Ruan and Chunhua Lu [2] found that ultimate flexural capacity of GFRP concrete beams was nearly 91-97% of that of steel reinforced concrete beams. Hadi et al. concluded that the ultimate load of the concrete beams fabricated with pultruded GFRP grating mesh ranged between 19-38% higher than the ultimate load of the beams produced with steel rebars [3].

At Kennesaw State University, complex experimental and analytical studies of stress-deflection state, the formation and development of normal cracks on concrete beams produced with two different concrete mixtures and two different types of reinforcement have been carried out. This study investigates the flexural behavior of concrete beams reinforced with two different types of reinforcement—traditional #4 (13 mm) steel rebar and #4 (13 mm) Greenbar fiberglass rebar—combined with two distinct concrete mixtures. All beams were fabricated using Type I cement and were tested to failure upon reaching a prescribed value of compressive strength of 4000 psi (27.6 MPa). The experimental program was focused on evaluating key performance metrics, including load-deflection behavior, ultimate load capacity, and ductility. The results provide comparative insight into the structural effectiveness of steel and fiberglass reinforcement under standardized loading conditions, contributing to ongoing discussions on the viability of non-metallic reinforcements in structural applications.

2. MATERIAL

Two types of reinforcement were used in this research Greenbar2X Fiberglass Rebar #4 and Steel Rebar #4. Fiberglass Rebar has higher tensile strength and durability with lighter weight in comparison to steel rebar. Two different types of concrete mixtures were investigated with the granite as aggregate [4] as shown in Tables 1 and 2. The second concrete mixture had Fly Ash as a replacement of 30% of cement.

Water to cement ratios for all concrete beams was 0.32 with compressive strength of concrete of 4000psi (27.6 MPa). Type I cement was used in this research. Compressive strength was reached after 9 hours. Granite was used as aggregate with 100% passing the 3/8 in sieve. Prior to the casting operation, all the material was dried in an oven to gain consistency in mixture proportions. The aggregates were dried in an oven at 200 deg Fahrenheit for approximately 24 hours to ensure the moisture content was zero. After drying, the aggregates were then stored in a dry storage container until they were used for batching.

Two hours before the mixing operation, the materials were weighed and stored in buckets located in a temperature-controlled room until the concrete was batched. This procedure ensured consistency in batch temperature and almost the same slump for all mixes [4, 5, 6].

To mitigate plastic shrinkage, MasterFiber M100 was added to both concrete mixtures. The slump test was conducted immediately before casting, yielding a value of 7 inches (17.8 cm).

Table 1. Concrete Mix Design #1

Material	Weight lbs/yd^3 (kg/m^3)
Cement	813.8 (482.8)
Water	260.4 (154.5)
Crushed Granite	1447 (858.5)
Sand	1447 (858.5)
HRWR	81 fl.oz/yd^3 38.8ml/m^3
MasterFiber M100	0.50 (0.3)

Table 2. Concrete Mix Design #2

Material	Weight lbs/yd^3
Cement	572.5 (339.3)
Fly Ash	241.3 (143.2)
Water	260.4 (154.5)
Crushed Granite	1447 (858.5)
Sand	1447 (858.5)
HRWR	81 fl.oz/yd^3 38.8 ml/m^3
MasterFiber M100	0.50 (0.30)

3. METHODOLOGY

This experimental study was designed to investigate the flexural behavior of concrete beams reinforced with two different types of longitudinal reinforcement: traditional steel and fiberglass rebar. A total of two beam specimens were fabricated using identical dimensions and concrete mix design, with the only variable being the type of reinforcement as shown in Figure 1.

Each beam had a square cross section measuring 6 in × 6 in (15 cm × 15 cm) and a total length of 5 ft (1.52 m). One beam was reinforced with a conventional #4 (13 mm diameter) steel rebar, while the other incorporated a #4 (13 mm) Greenbar fiberglass rebar, a composite material commonly used in corrosion-resistant applications. After casting, the beams were moist-cured under controlled laboratory conditions until the concrete reached a target compressive strength of 4000 psi (27.6 MPa), at which point they were tested to failure.

Figure 1. Beam Cross Section a) Fiberglass #4 as reinforcement b) Steel Rebar #4 [7]

Flexural testing was conducted in accordance with ASTM C293, employing a center-point loading setup to measure the Modulus of Rupture. During testing, key parameters including load-deflection response and maximum load capacity were recorded. Comparative analysis was performed to assess the influence of reinforcement type on the structural performance of the beams under flexural loading.

Figure 2. Concrete Beam Setup

4. RESULTS

This research was focused on investigation of the beams produced with different type of reinforcement and concrete mixtures. Fiberglass #4 and Steel Rebar #4 were used in testing, and concrete mixture having angular aggregate and Microfiber and concrete mixture with fly ash as a replacement of cement. Three-point flexural tests were done in order to understand the effect of different type of reinforcement and concrete mixtures on Modulus of Rupture. The experimental results reveal varied mechanical responses across specimens, highlighting differences in stiffness, ductility, and load capacity.

All specimens exhibited an initial elastic response marked by proportional increases in displacement with load. Mix#1 with Fiberglass and Mix#2 with Steel Rebar showed higher maximum load capacities of 4400 lbs (19.57 kN) and 4800 lbs (21.35 kN), respectively, while Mix #1 with Steel Rebar and Mix #2 with Fiberglass reached lower peak loads of 3000 lbs (13.34 kN) and 1000 lbs (4.45 kN).

Table 3. P-δ values Mix #1 with Fiberglass

P (lbs) (kN)	δ (in) (cm)
460 (2.05)	0.041(0.10)
960 (4.27)	0.183 (0.46)
1200 (5.34)	0.240 (0.61)
1500 (6.67)	0.299 (0.76)
2000 (8.89)	0.451 (1.14)
2500 (11.12)	0.552 (1.40)
3000 (13.34)	0.562 (1.43)
3500 (15.57)	0.569 (1.44)
4000 (17.79)	0.565 (1.44)
4400 (19.57)	0.548 (1.39)

Table 4. P-δ values Mix #1 with Steel rebar

P (lbs) (kN)	δ (in) (cm)
350 (1.56)	0.045 (0.11)
730 (3.25)	0.177 (0.45)
1000 (4.45)	0.216 (0.55)
1500 (6.67)	0.284 (0.72)
2000 (8.90)	0.389 (0.99)
2500 (11.12)	0.497 (1.26)
3000 (13.34)	0.606 (1.54)

Table 5. P-δ values Mix #2 with Steel rebar

P (lbs) (kN)	δ (in) (cm)
350 (1.56)	0.014
530 (2.36)	0.069
850 (3.78)	0.092
1050 (4.67)	0.122
1500 (6.67)	0.149
2000 (8.90)	0.190
2500 (11.12)	0.224
3000 (13.34)	0.228
3500 (15.57)	0.243
4000 (17.79)	0.289
4800 (21.35)	0.473

Table 6. P-δ values Mix #2 with Fiberglass

P (lbs) (kN)	δ (in) (cm)
500 (2.22)	0.074 (0.20)
1000 (4.45)	0.162 (0.41)

Mix #1 with Steel rebar showed a more gradual and ductile response with steady displacement increase up to 3000 lbs (13.34 kN), without clear softening.

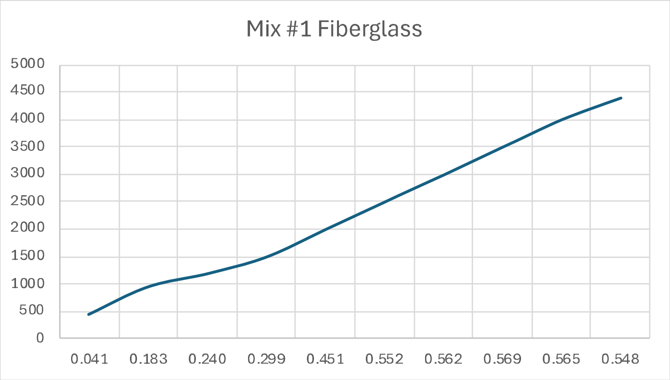

Figure 3. P-δ diagram for Mix #1 produced with Fiberglass

Mix #1 with Fiberglass demonstrated early stiffness followed by a plateau in displacement beyond 2500 lbs (11.12 kN), suggesting onset of softening.

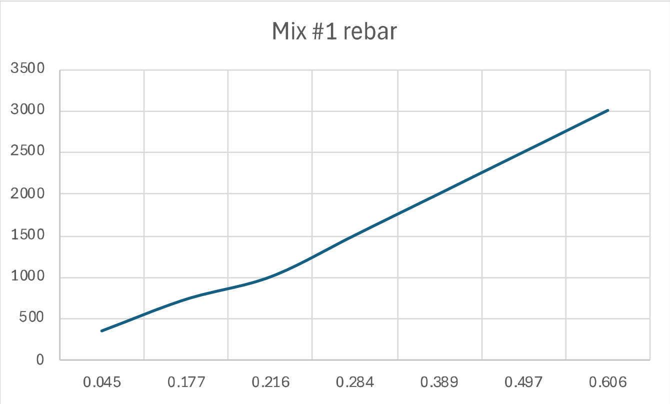

Figure 4. P-δ diagram for Mix #1 produced with Steel Rebar

Mix #2 with Steel rebar sustained the highest load, with displacement increasing gradually and reaching 0.473 in (1.20 cm) at 4800 lbs (21.35 kN), showing strong stiffness retention.

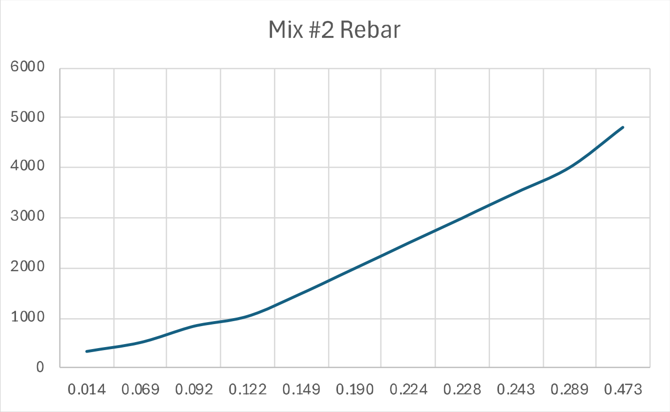

Figure 5. P-δ diagram for Mix #2 produced with Steel Rebar

Mix #2 with Fiberglass was tested only up to 1000 lbs (4.45 kN), aligned with early-stage elastic behavior observed in other specimens, confirming consistency in initial stiffness.

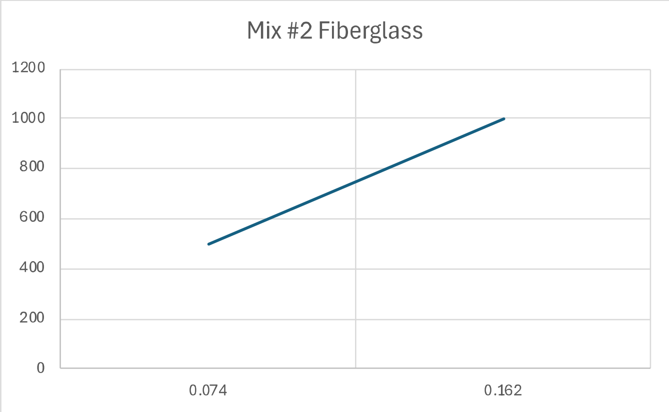

Figure 6. P-δ diagram for Mix #2 produced with Steel Rebar

The Modulus of Rupture values were as follows: Mix #1 reinforced with fiberglass achieved 1833 psi (12.64 MPa), Mix #1 with steel rebar reached 1250 psi (8.61 MPa), Mix #2 with steel rebar recorded 2000 psi (13.79 MPa), and Mix #2 reinforced with fiberglass measured 416 psi (2.87 MPa).

5. CONCLUSIONS

This study evaluated the load–displacement behavior of four structural specimens under monotonic loading. The experimental results revealed notable differences in mechanical responses, which can be summarized as follows:

- Mix #1 with Fiberglass and Mix #2 with Steel Rebar demonstrated the highest load capacities, reaching 4400 lbs (19.57 kN) and 4800 lbs (21.35 kN), respectively. Mix #1 with Fiberglass exhibited early stiffness with a subsequent plateau, indicating potential damage or softening, whereas Mix #2 with Steel Rebar maintained stiffness with a gradual displacement increase, suggesting enhanced structural resilience.
- Mix #1 with Steel rebar showed a stable and ductile response with moderate peak load (3000 lbs or 13.34 kN), indicating consistent deformation without early loss of strength.
- Mix #2 with Fiberglass, limited to lower load levels, confirmed the initial elastic stiffness trend common across all specimens, serving as a baseline for early-stage structural behavior.

The observed variability among specimens emphasizes the influence of material properties, geometric factors, or boundary conditions on structural performance. These findings underscore the importance of testing multiple specimens to comprehensively characterize load-bearing capacity and deformation behavior.

Overall, the results provide valuable insight into the load bearing and deformation characteristics of the tested materials, informing design considerations and further investigations aimed at improving structural reliability and safety.

The differences in behavior also highlight the potential of hybrid reinforcement systems in tailoring structural performance for specific applications. Future research may explore cyclic loading conditions, long-term durability, and the effects of scale to better simulate real-world performance. Additionally, finite element modeling could be used to complement experimental findings and refine predictive models.

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