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Evaluation of the Use of Geosynthetic Systems in the Improvement of Reinforced Concrete Beams at Elevated Temperature

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KEYWORDS

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ABSTRACT

This project evaluates the use of geosynthetic systems to improve the performance of reinforced concrete beams subjected to elevated temperatures. As concrete remains a fundamental material in construction, its vulnerability to thermal degradation poses significant risks, particularly in fire scenarios and extreme environmental conditions. This study aims to investigate how incorporating geosynthetic materials can enhance the mechanical properties and durability of reinforced concrete structures under high-temperature exposure. The research employed experimental methods, including compressive and flexural strength tests on concrete samples with and without geosynthetic reinforcement. Specimens were subjected to temperatures of 300°C and 600°C to assess their performance. The results demonstrated that geosynthetic reinforcement signinificantly improved both compressive strength (Sample C vs A, 31.2 N/mm^2 vs 29.8 N/mm^2) and flexural strength (Sample C vs A, 35.56 N/mm^2 vs 33.33 N/mm^2) at room temperature (25°C). Notably, geosynthetic reinforcement significantly reduced the percentage loss of compressive strength after thermal exposure. Plain concrete beam (A to B) showed a 20.4% decline, while geotextile reinforced sample (C to D) showed only a 9.6% decline in compressive strength, an indication of a better thermal protection. Results demonstrated that geosynthetic reinforcements significantly mitigated the loss of compressive and flexural strength due to thermal exposure, while also enhancing ductility and delaying crack propagation. The findings underscore the potential of geosynthetic systems to optimize the design and safety of reinforced concrete structures in high-temperature environments.

24. INTRODUCTION

The use of reinforced concrete structures is ubiquitous in modern construction, owing to their strength, durability, and versatility (ACI 318, 2019). However, these structures may be susceptible to the negative effects of high temperatures, such as those found in industrial settings, high-rise buildings, and fires (Kodur & Bhatt, 2023). Exposure to high temperatures can lead to degradation of the concrete, loss of structural integrity, and potential failure of the reinforced concrete elements (Kodur & Bhatt, 2023). Designing reinforced concrete structures with appropriate levels of redundancy and alternative load paths is crucial to maintain structural stability and prevent catastrophic failures during fire events (Franssen & Gernay, 2017). One proposed solution for addressing this challenge is the use of geosynthetic materials within the reinforced concrete system. Geosynthetics, such as geotextiles, geogrids, and geomembranes, have shown the ability to enhance the mechanical properties, thermal insulation, and fire resistance of construction materials (Jones & Dixon, 2023). Nonetheless, the effectiveness of utilizing geosynthetic systems to improve the performance of reinforced concrete structures under elevated temperature conditions has not been widely studied (Abu-Farsakh, 2024). Consequently, this project is set to assess the use of geosynthetic systems in the improvement of reinforced concrete beams at elevated temperature.

25. MATERIALS AND METHODS

2.1 Materials and Equipment

The materials for this research work were carefully sourced and selected from both Ogun and Lagos States in order to ensure absolute compliance with relevant codes and specifications. Statistical Package for the Social Sciences (SPSS) software was used to analyse the results.

2.1.1 Cement

The cement used for this research was Dangote 3X 42.5N Ordinary Portland Cement.

2.1.2 Fine Aggregate

Clean river sharp sand in accordance to BS 882 was obtained from Sagamu in Ogun State for this research.

2.1.3 Coarse Aggregate

Clean crushed granite of 19mm diameter maximum particle size obtained from a construction site was used in batching of the concrete samples for this research work.

2.1.4 Water

Clean, drinkable water in accordance to BS EN 1008: 2002 was obtained from Makun City and used for this research.

2.1.5 Geotextile

Polyethylene Terephthalate (PET) woven geotextile with 200 – 400 KN/m strength and stable up to 150ºC was obtained from Polage Infravest, in Lagos for this research.

2.1.6 Reinforcement

The steel used for this research were 12mm and 10mm diameter main bar and stirrup in beam in conformity to BS 4449. The tensile strength of the steel bars were within 410 – 460N/mm2.

2.2.1 Concrete Batching

The concrete batching for the specimen was by volume, using cement-fine aggregate-coarse aggregate ratio (1:1:2) with a target compressive strength of 30N/mm^{2}in 28 days. The cement-water ratio was 0.5 for the mix.

2.2.2 Determination of Mechanical Properties of Reinforced Concrete

In this research, both compressive and flexural test were carried out on the specimen at different temperature condition in order to investigate mechanical properties of the conventional specimen and the geotextile reinforced specimen. In order to determine the compressive strength, 36 samples of concrete cubes were cast, 16 were plain concrete, while 16 samples contain a single layer of PET woven geotextile reinforcement placed at the neutral axis. At each curing ages (7, 14, 21, and 28 days), 2 samples each of plain concrete at room temperature of 25ºC (Sample A), plain concrete at elevated temperature of 300ºC (sample B), geotextile reinforced concrete at room temperature of 25ºC (Sample C), and geotextile reinforced concrete at elevated temperature of 300ºC (Sample D) were tested for compressive strength and the result for each curing age were recorded.

Plate 1: Heating of concrete cubes

Plate 2: Compressive test of concrete cubes

In this research, four R.C. Beam samples of (1000mm x 150mm x 150mm) were cast. Samples (beam A and beam B) had only nominal steel reinforcement, while the other two samples (beam C and beam D) contain both nominal steel and a single layer of PET woven geotextile reinforcement at the neutral axis.

All the four beam specimen were cured for 28 days. At 28 days, both Beam A and Beam C were tested for flexural strength at room temperature of 25ºC.

Plate 3: Concrete beam heated to 600°C

In contrast, beam B and beam D were heated to an elevated temperature of 600ºC for 2 hours at 28 days curing age, both samples were thereafter allowed to cool and tested for flexural strength.

Plate 4: Rebound hammer test on beam

Plate 5: Beam sample under flexural testing

Plate 6: Cracks on beam during flexural test

Visual observation of beam samples B and D at elevated temperature of 600⁰C under increased loading revealed the crack development in the beam starting at the mid-span where the bending moment is maximum and the shear is minimum. The flexural cracks at the mid-span got widened and spread towards the support at increased loading, showing a diagonal tension crack near the support as observed in Plate 6. This show alteration in the failure mode of the beam samples B and D from flexural to shear/flexural.

3. RESULTS AND DISCUSSION

Visual observation of beam samples B and D at elevated temperature of 600⁰C under increased loading revealed the crack development in the beam starting at the mid-span where the bending moment is maximum and the shear is minimum. The flexural cracks at the mid-span got widened and spread towards the support at increased loading, showing a diagonal tension crack near the support as observed in Plate 6. This show alteration in the failure mode of the beam samples B and D from flexural to shear/flexural.

3.1 Compressive Strength Test

Table 1: Compressive Test Result of Sample A

SAMPLE A: Plain Concrete at room temperature.					
Days of Curing	Temperature (⁰C)	Weight (Kg)	Rebound Number	Maximum Load (KN)	Compressive Strength (N/mm²)
7	25	2.60	20	201	20.1
14	25	2.57	21	266	26.6
21	25	2.55	28	283	28.3
28	25	2.58	21	298	29.8

Table 2: Compressive Test Result of Sample B.

SAMPLE B: Plain Concrete at elevated temperature.					
Days of Curing	Temperature (ºC)	Weight (Kg)	Rebound Number	Maximum Load (KN)	Compressive Strength (N/mm²)
7	300	2.58	15	165	16.5
14	300	2.55	16	214	21.4
21	300	2.59	20	227	22.7
28	300	2.55	16	237	23.7

Table 3: Compressive Test Result of Sample C.

SAMPLE C: Concrete with Geotextile at room temperature.					
Days of Curing	Temperature (ºC)	Weight (Kg)	Rebound Number	Maximum Load (KN)	Compressive Strength (N/mm²)
7	25	2.60	20	212	21.2
14	25	2.58	21	280	28.0
21	25	2.60	28	299	29.9
28	25	2.58	21	312	31.2

Table 4: Compressive Test Result of Sample D.

SAMPLE D: Concrete with Geotextile at elevated temperature.					
Days of Curing	Temperature (ºC)	Weight (Kg)	Rebound Number	Maximum Load (KN)	Compressive Strength (N/mm²)
7	300	2.55	19	192	19.0
14	300	2.60	19	251	25.1
21	300	2.55	26	268	26.8
28	300	2.58	19	282	28.2

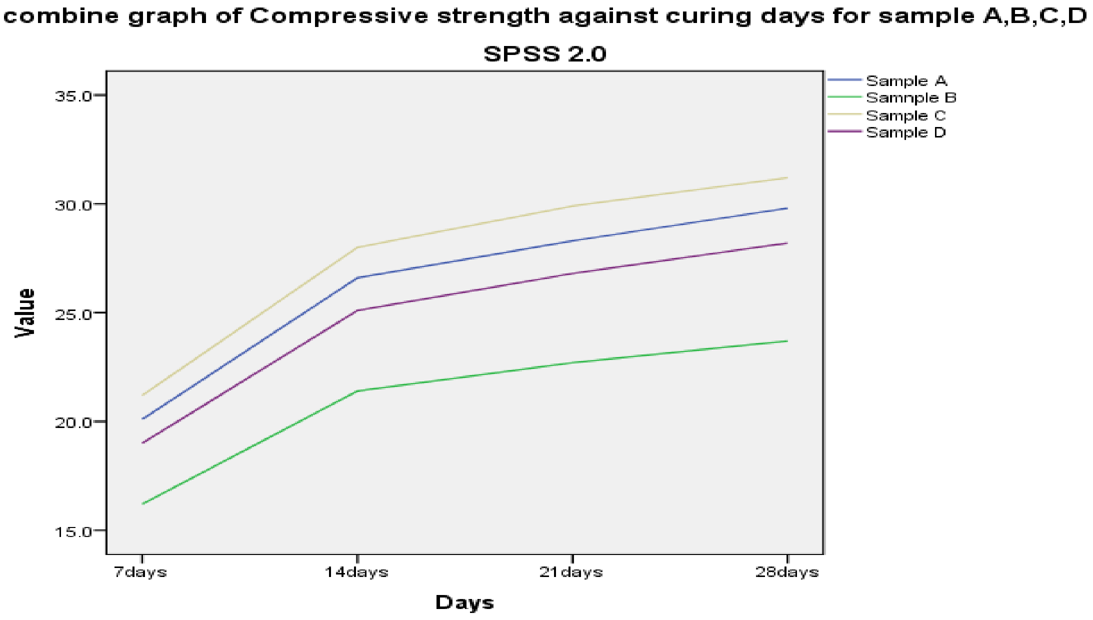


Figure 1: Combine graph of compressive strength against curing days for sample A,B,C,D.

The results from the tables 1 - 4 showed that both plain and the geotextile reinforced samples exhibited a substantial decline in mechanical robustness when exposed to elevated temperatures.

Plain concrete (sample A and B) had a drop of compressive strength from 29.8 MPa at room temperature of 25ºC to 23.7 MPa at 300ºC (a 20.4% decrease). Geotextile reinforced concrete (sample C and D) had a drop of compressive strength from 31.2 MPa at room temperature of 25ºC to 28.2 MPa at 300ºC (a 9.6% decrease). Although there is thermal degradation of structural integrity in both samples at elevated temperature, it is less severe in the geotextile reinforced concrete samples. Also, the geotextile reinforced samples had a significantly higher compressive strength in contrast to the plain concrete samples.

The graph in figure 1 shows a comparative view of compressive strength development across all samples (A, B, C, D) over the curing period. Differences in the slopes of the curves and the final strengths show the influence of the geotextile on hydration and reinforcement efficiency.

3.3 Flexural Strength Test

Table 5: Flexural strength result (one point loading)

Beam Sample	Temperature (ºC)	Deflection (mm)	Ultimate Load (KN)	Flexural Strength (N/mm²)
A	25	10.8	75.00	33.33
B	600	11.2	45.00	20.00
C	25	9.9	80.00	35.56
D	600	8.2	60.00	26.67

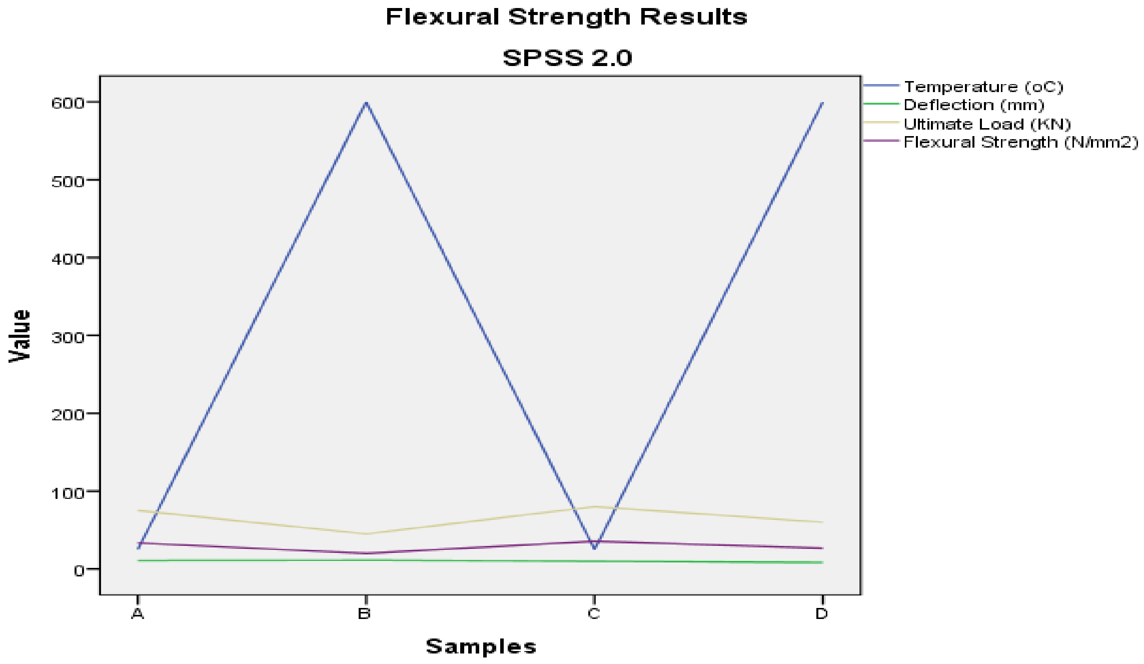


Figure 2: Diagram showing graph of flexural strength result

Table 5 shows the flexural strength results of all the beam specimens and in Figure 2 is the graph which compares the flexural strength of the beams (A, B, C, D). The graph in Figure 2 shows that geosynthetic reinforcement enhances flexural strength as observed in samples C and D in contrast to control samples A and B. Variations among the samples at both room and elevated temperature indicate the effectiveness of geosynthetics in bridging cracks and improving tensile resistance.

3.4 Load – Deflection Results

Table 6: Load-Deflection of Beam A.

Beam Sample A								
Load (KN)	10	20	30	40	50	60	70	75
Deflection (mm)	1.0	1.9	3.0	4.3	5.2	6.5	9.4	10.8

Table 7: Load-Deflection of Beam B.

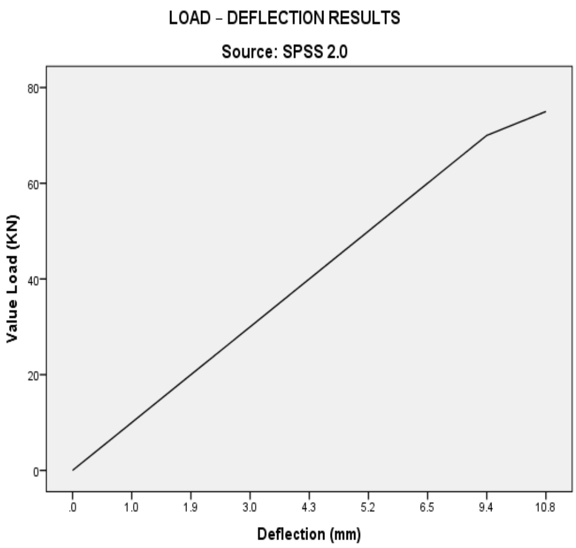
Beam Sample B						
Load (KN)	0	10	20	30	40	45
Deflection (mm)	0	1.2	2.6	5.0	8.3	11.2

Table 8: Load-Deflection of Beam C.

Beam Sample C								
Load (KN)	10	20	30	40	50	60	70	80
Deflection (mm)	0.6	1.5	2.6	3.5	4.4	6.0	8.1	9.9

Table 9: Load-Deflection of Beam D.

Beam Sample D							
Load (KN)	0	10	20	30	40	50	60
Deflection (mm)	0	0.8	1.9	3.0	3.8	5.7	8.2



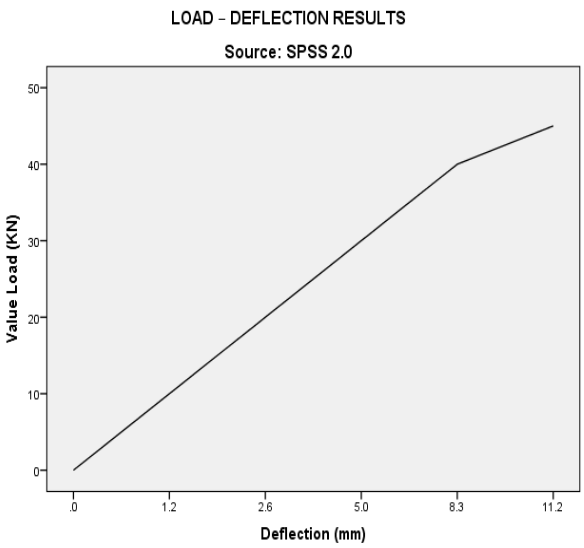
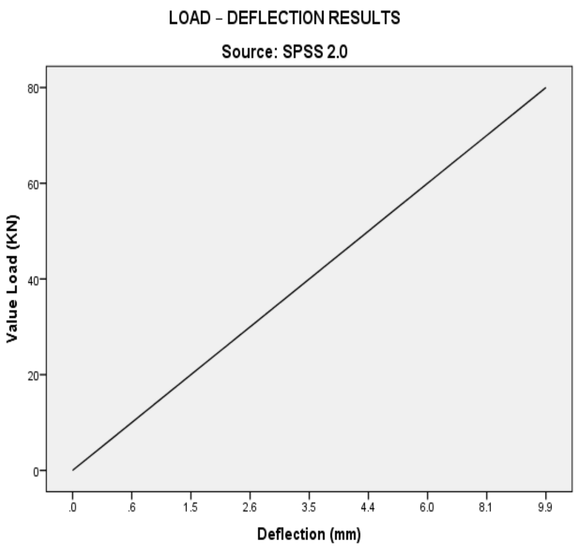


Figure 3: Load-Deflection of Beam A

Figure 4: Load-Deflection of Beam B



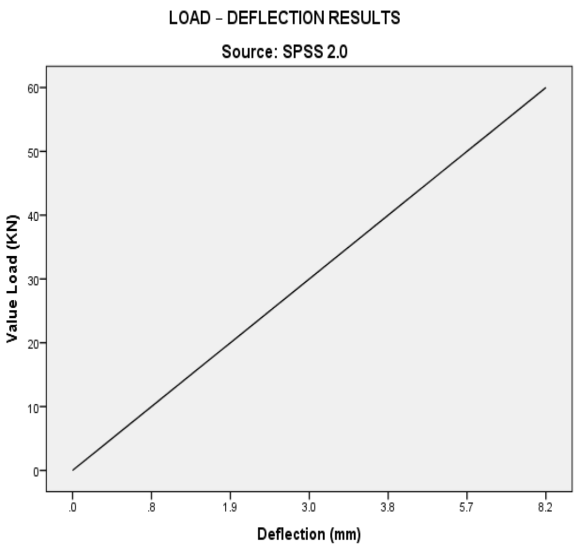


Figure 5: Load-Deflection of Beam C Figure 6: Load-Deflection of Beam D

Tables 6, 7, 8, and 9 show the load-deflection results of beams (A, B, C, D) respectively. Figures 3, 4, 5, and 6 are the graphical illustrations of the load-deflection behavior of all the beams under flexural loading. In beams A and B, the curve typically has an initial linear elastic region, followed by a non-linear portion after cracking, and then a plateau or drop at failure. In beams C and D, the area under the curve is non-linear. Deflections increased disproportionately to increased loading at the initial stage of crack to after the onset of cracking.

The shape of the curve reveals ductility and post-cracking performance, which are influenced by the geosynthetic reinforcement in sample C.

Differences in the peak load, deflection at failure, and the post-peak behavior compared to specimen A reflect the impact of geosynthetics on ductility and energy absorption. A more gradual drop after peak load suggests better crack control and ductility. A flatter post-cracking curve indicates superior reinforcement, allowing for greater deflection without sudden failure.

3.5 Rebound Hammer Test

Table 10: Rebound Mean Values of Cube Samples

Sample	A	B	C	D
Mean Value	22.50	16.50	22.50	20.75

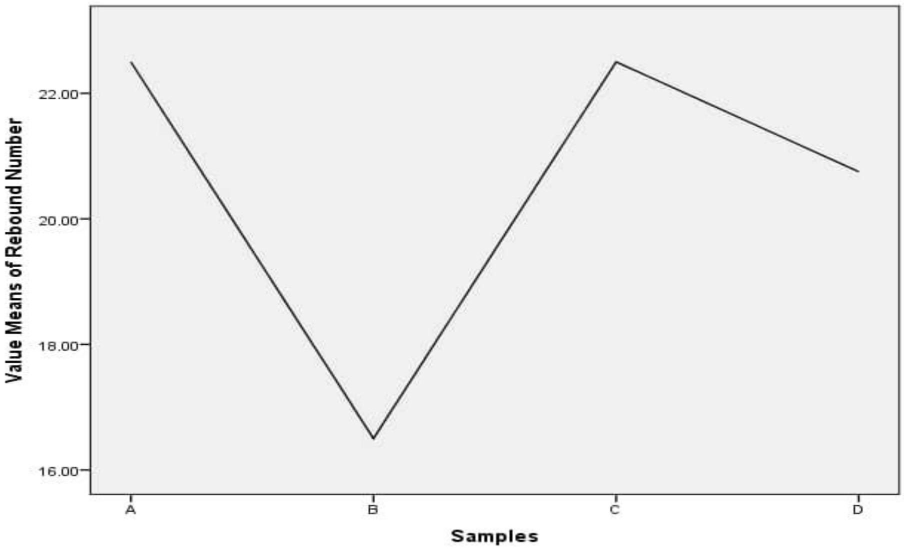


Fig 7: Diagram showing means of Rebound Number

Table 10 shows the mean values of rebound number of the concrete cube samples. Rebound hammer tests provide a non-destructive estimate of surface hardness, which correlates with compressive strength.

Figure 7 is the graphical representation of the means of the rebound number value of the samples. Higher rebound numbers was observed in Sample A and C which generally indicate higher surface hardness and, by correlation, higher compressive strength. Sample B had the lowest average rebound number which is an indication of lowest compressive strength among the samples.

Variations among samples reflect differences in surface quality or the influence of geosynthetics on the mechanical properties as observed in Sample C and D which both had high average rebound values in contrast to both Samples A and B.

4. CONCLUSION

This research work was able to establish the following conclusions:

1. Concrete batching with geosynthetic reinforcement produces better strength than the conventional plain concrete batching method.
2. Geosynthetic reinforcement improves both compressive and flexural strength of concrete at normal temperatures (25°C).
3. Exposure to elevated temperatures (300°C for cubes, 600°C for beams) significantly reduces both compressive and flexural strength.
4. Geosynthetic reinforcement provides a protective effect, mitigating the strength loss caused by elevated temperatures. Reinforced samples retain higher strength after heating compared to unreinforced samples exposed to the same temperature.
5. Severe heating (600°C) alters the failure mode of beams from flexural to shear/flexural and reduces their ductility, though geosynthetics still improve performance compared to unreinforced beams.
6. Geosynthetic-reinforced concrete exhibits higher initial stiffness under flexural loading.

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