EDSU Journal of Engineering and Technology (EDSUJET)

Reliability of Flexural Behaviour of Reinforced Concrete Waffle Slab Containing Chemical Polymer Additive

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Received: 16th September 2025, Accepted: 30th October 2025, Published: 30 November 2025

KEYWORDS

Furan polymer
Reinforced Concrete waffle slab (RCWS)
Reliability Index (β)
Compressive strength
Flexural strength

ABSTRACT

This study examined the flexural strength of reinforced concrete waffle slabs incorporating Furan chemical polymer at varying replacement levels of 0%, 1%, 1.5%and 2.0%. A total of 48 concrete cubes 150x150mm and slabs 500x350mm were tested through compressive, slump, and flexural strength evaluations. Results showed that compressive strength increased with Furan addition up to 1.0% ranging from 24.9 N/mm² to 40.6 N/mm² but dropped significantly at 2.0% replacement (14.1-23.0N/mm²). Flexural tests indicated that load capacity improved up to 1.5% Furan but declined beyond that level, with increased deflection observed at 2.0% replacement. The optimal performance occurred between 1.0% and 1.5% Furan, where slabs exhibited higher load-bearing capacity and reduced deflection compared to the control mix. It was concluded that moderate Furan incorporation enhances concrete performance, while excessive use weakens structural behavior. Further research is suggested to explore Furan polymers derived from natural residues such as corn cobs, rice husks, and Vernonia amygdalina extracts.

26. INTRODUCTION

Reinforced concrete slabs are essential structural elements used in buildings, bridges, and other infrastructures to support vertical loads from occupants, furniture, materials, and vehicles. In modern structures especially high-rise and underground buildings slabs also function as floor diaphragms, resisting horizontal forces such as wind, seismic loads, and soil pressure. Their design involves various data and safety factors to ensure both economy and structural reliability (Verma&Bhatnagar,2014).

Reducing slab construction costs can lead to significant savings in materials, labour, and time, as well as reductions in the costs of other structural elements (Adenuga & Sotunbo, 2014; Anjaneyulu & Prakash, 2016 Bhatia & Golait,2016; Bhowmik et al., 2017). The cost of reinforced slabs varies depending on usage type, span direction, support conditions, and construction methods (Ogyiri, 2018; Nyong, 2019). Major cost factors include concrete volume, reinforcement, and formwork, all of which increase with greater slab spans and higher concrete compressive strength (Galeb & Saeed,2020).

Waffle slabs concept evolved from traditional two-way slab systems, aiming to reduce weight and material usage while maintaining high load-bearing capacity. Principally, static analysis of waffle floor aim to determine the amount and distribution of shear forces bending moment and torsional moments acting on the structure (Galeb AC, 2011).

27. MATERIALS AND METHODS

In order to accomplish this research's objectives, materials such as Cement (Ordinary Portland Cement), Coarse Aggregate (Granite), Fine Aggregate (Sharp Sand), Water and Reinforcement Furan polymer. were sourced and carefully selected from different location within Lagos Sate.

2.1.1 Furan

The chemical polymers (furan) obtained from Ojota Chemical Market

Furan: Physical Properties

Colour: White, flammable, Odor ether-like

Furan: Chemical Properties

Highly volatile with boiling point close to room temperature (31.3 degree °C). melting point -85.6 degree °C, density 0.936g/ml, Molecular weight 68.07g/mol.

2.1.2 Formwork

Slab dimension 1000x350x125mm, rectangular framed marine board with Styrofoam arrayed as pods. Plate 1 shows the formwork of the waffle slab.

Plate 1 Formwork for waffle slab with wood edges and wooden pods

2.2 EXPERIMENT PROCEDURE

All the laboratory work was carried out to determine the concrete strength, flexural strength slump test, sieve analysis, Auto cad was used to develop the architectural floor plan used for the design, the floor was scaled down to 1:20 and 1:10 for wooden formworks to size for the purpose of obtaining suitable sizes for flexural test

2.3 Concrete Design Mix

Selection of mix proportions for this research work carried out using empirical procedures based on trial mix, 1:1.5:3.9 for the purpose of this research mixing ratio and water-cement ratio of 25: 50= 0.5 was adopted. The Plate 2, and 3 shows the preparation and casting of the concrete cubes while Table 1 shows concrete samples mix ratio while slump test result is shown in table 2.

Plate 2 weighing of Granite

Plate 3 weighing of Granite

Table 1: Concrete Design Mix

Material	0% Furan	1%Furan	1.5%Furan	2%Furan
Water (kg)	**25**	**25**	**25**	**25**
Cement (kg)	**50**	**50**	**50**	**50**
Sharp sand (kg)	**75**	**75**	**75**	**75**
Granite (kg)	**195**	**195**	**195**	**195**
Furan (g)	**0**	**250**	**375**	**500**

Table 2: Concrete Design Mix

Furan Replacement	Cone height(mm)	Measure height(mm)	Slump (mm)	Slump percentage (%)
0%Furan Replacement.	300	265	35	13.2
1.0%Furan Replacement.	300	263	37	14.1
1.5 %Furan Replacement	300	267	33	12.4
2.0%Furan Replacement	300	264	36	13.6

2.4 **Determination of Compressive and Flexural Resistance of Waffle Slabs With and Without Chemical Polymer**

The flexural test for a Reinforced Concrete Waffle RCW floor was carried out in University of Lagos. The sample waffle floor measures 1000x350x125mm. The slab was reinforced with 8mm. concrete grade will be 1:1.5:3.9. the waffle slabs were cured by covering with wet Jude bags for 28days. Plate 2 shows the curing of the sample slabs with Jude bags,

Plate 4 Curing of Slab with Wet Jute Bags

2.5 Setting up the Load frame test

Load frame test the slabs are tested in the loading frame of 100tons loading capacity and end conditions were set as simply supported and functioning of the LVDT and strain gauge. After all the initial settings are carried out the load is applied on the center of the panel as shown in

Fig. 1 and plate 5, Plate 6 shows the Set-up waffle slab ready for flexural test as guided by ASTM 293C code while plate 7 captures the reading of ultimate strength and deflection from the dial gauge. The panel was setup as guided with all the primary settings checked was done before placing on the LVDT and strain gauge. After all the initial settings were carried out the load is applied on the center of the slab until cracking is observed, the crack patterns were observed and noted as

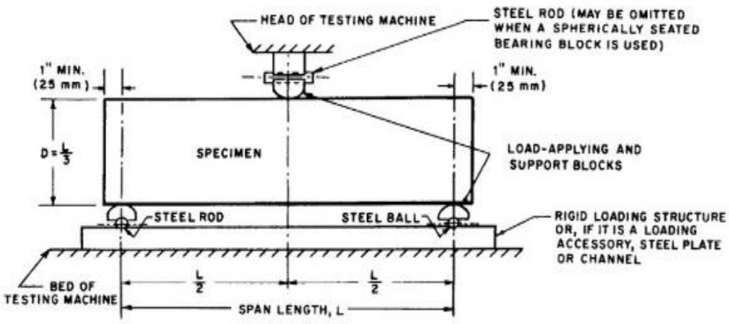

Figure 1.0: Apparatus for flexural test of concrete by center point loading method

Plate 5: Marking off support and load path as guided by ASTM 293C code

Plate 6: Setting up waffle slab for flexural test as guided by ASTM 293C code

Plate 7: Set up waffle slab ready for flexural test as guided by ASTM 293C code

Plate 8: Reading out values of ultimate load and deflection from dial gauge

Plate 9: Crack Patterns Developed

3.0 RESULTS AND DISCUSSION

3.1 Compressive strength with Furan Replacement

Table 3.0 shows increase in compressive strength from 0%, 1% 1.5% furan replacement while significant decrease was observed from samples between 1.5% and 2% furan replacement.

Similarly, in figure 2.0, The load bearing capacity of the waffle slab from 2% Furan Polymer replacement was observed to decrease judging from the value the deflection measured from the dial gauges, as specimens having 2.0% furan polymer replacement was observed to have more deflection.

Table 3: Compressive strength of concrete with furan replacement vs curing days

Days of curing	Applied Force (KN)	**0% replacement**	**1% replacement**	**1.5% replacement**	**2% replacement**
0	860.2	0.0	0.0	0.0	0.0
7	913.0	24.9	26.4	20.2	14.1
14	604.5	36.1	38.8	28.8	18.8
28	519	38.3	40.6	31.0	23

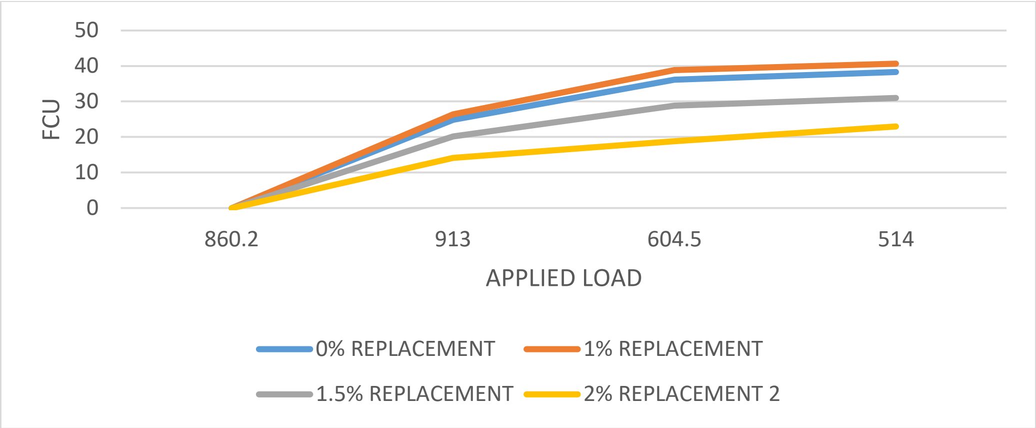

Figure 3: comparing compressive strength of concrete with and without furan replacement

Figure 3 shows that 1.0% furan replacement indicated the highest compressive with an increase from 26.4 to 40.6 N/mm^2 while compressive strength started receding from 2.0% furan replacement.

3.2 Area of Steel at Deterministic and Area of Steel at Reliability Vs Applied Load

Table 4 shows that furan polymer additives improve structural rigidity and stiffness of the slab, thereby reducing cost, and lowering self-weight of concrete. Relationship between applied force with area of steel in deterministic and reliability design.

From the result obtained it is observed that the higher the applied force the higher the moment of resistance which is directly proportional to area steel, the maximum fcu (compressive strength) was 40.6N/mm^2 with 1.0 % furan replacement, this indicate that furan at between 1.0% to 1.5% has an improved compressive strength.

Table 4 Applied force versus Area of steel in Deterministic and Reliability

%Furan	Moment KN.m	Area of steel provided (Deterministic)	Area of steel provided (Reliability)
0.0%	69.47	943	1056
1.0%	118.18	1410	1579.2
1.5%	101.12	1570	1411.1
2.0%	68.44	804	900.48

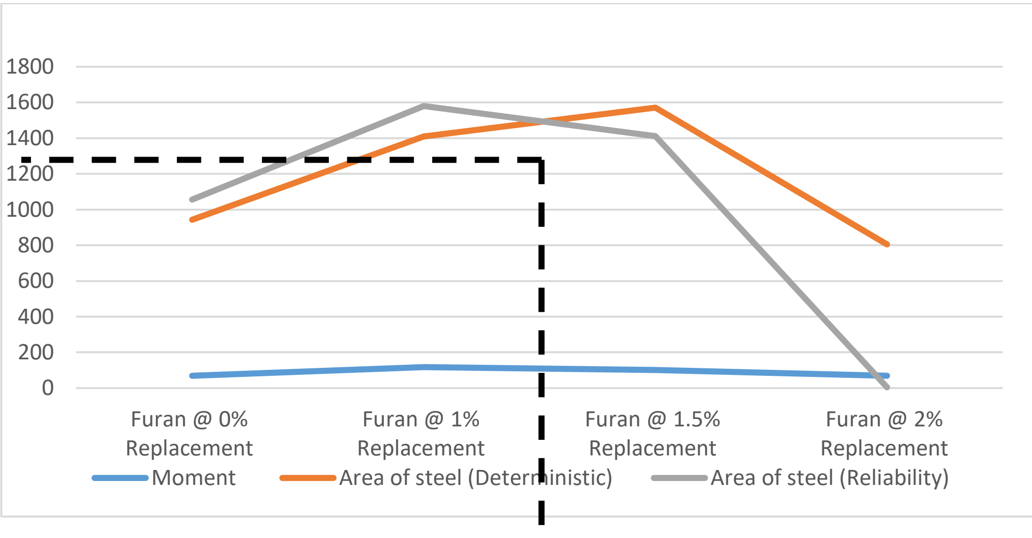

Figure 4 Applied force versus Area of steel in Deterministic and Reliability

Figure 4 show the relationship between force, area of steel in deterministic and area of steel in reliability, at 19.0KN/mm^2 applied load 943mm^2 area of steel (As) is required, although target strength is achieved at 2.0% Furan replacement which require 804mm^2 area of steel(As) but with a load carrying capacity with higher deflection. 1.0% and 1.5% furan replacement requires 1260 mm^2 and 1410 mm^2 respectively. As observed from the figure 4 1.0% and 1.5% furan replacement show a marginal increase in both strength and load carrying capacity, however started declining after 1.5% furan replacement. 4.3 Presentation of Reliability Based Design Approach and Discussion

Table 5 Fcu(characteristics of concrete), Deflection and Reliability Index

%FURAN REPLACEMENT	ULTIMATE FAILURE LOAD	DEFLECTION	RELIABILTY INDEX
0.0%	19.0	3.9	3.32
1.0%	35.0	1.7	3.43
1.5%	34.0	2.0	3.13
3.2.0%	38.2	2.3	2.53

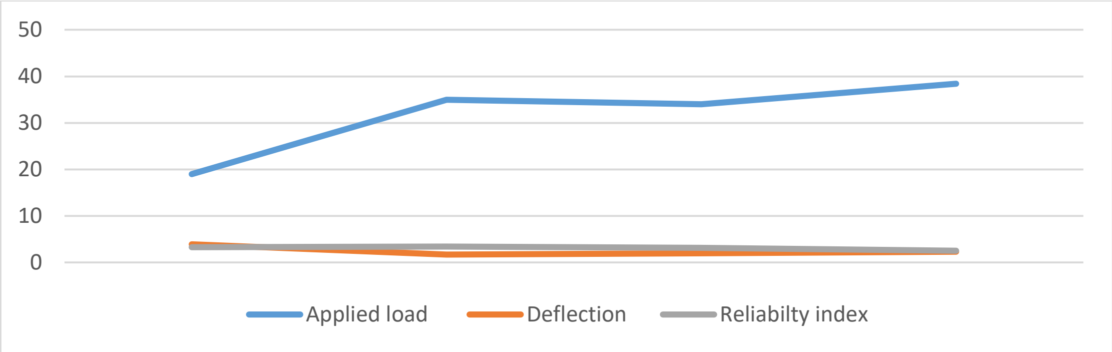

Figure 5 Relationship between furan % replacement with deflection reliability index

Table 5 shows that minimum deflection was observed 1.5% and 1.0% furan replacement which is between 1.7-2.0 mm, 0% indicate 3.9mm deflection with Fcu of 38.5N/mm^2 while 1.5% Furan replacement shows 2.0mm deflection with Fcu of 31N/mm2, this suggests that though 0% Furan replacement has higher Fcu but a lesser flexural rigidity. 1.5% Furan replacement has a lesser Fcu than 0% furan Replacement but a higher structural stiffness, as shown Figure 5

Under heavy load there are emergence of cracks within the concrete surface causing the stiffness to reduce. Thus, the deflection limit of the slab is reached earlier than under the normal loading conditions and would cause the slab to no longer satisfy the requirements for its serviceability limits.

4.0 CONCLUSIONS

Based on the values obtained from the tests carried the following points were concluded. It is inferred that the waffle slab system with Furan replacement between 1.0 and 1.5% show better load carrying capacity than 0% furan replacement under the same loading systems. Additional increase of Furan polymer after 1.5% resulted to higher deflection of slab which indicate a lower load carrying capacity of the waffle slab system. so, it can be concluded that ultimate strength is obtained when Furan Replacement between 1.0 and 1.5%.

ACKNOWLEDGEMENT

I wish to express my sincere gratitude to acknowledge the immense guidance of Engr. Professor John Wasiu and my reading partners Yemi and Wale thank you.

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