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# Analysis of flexural behavior of one-way reinforced concrete slab casted by shotcrete contain various types of plastic fibers

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ABSTRACT

The design of reinforced concrete structures has traditionally relied on empirical techniques based on experience or experimental research on actual structural members. Although this approach produces a high level of precision, it is usually exceedingly costly and time-consuming. This paper studied the convergence between theoretical analysis (ACI 318-19 Equations) and numerical analysis (FEM) of eleven one way reinforced concrete slab specimens casted by shotcrete contains three types of plastic fibers including waste plastic (PET), polypropylene (PP), and hybrid (PET+PP) fibers with three addition ratios (0.35%, 0.7%, and 1%) for each type. The results concluded that the numerical analysis (ANSYS FE model) showed a good agreement with the theoretical (ACI 318-19) of one-way slab in terms of ultimate load, with a variance, and standard deviation equal to 0.00076, and 0.027 respectively. Hence, ANSYS v15 software can be used for the analysis of reinforced concrete slabs casted by shotcrete contain waste plastic fibers and polypropylene fibers.

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## 1. Introduction

Nowadays, using numerical methods to analyze structural elements has become a very popular approach. With the advent of high-performance computers, Finite Element Analysis (FEA) gained popularity as a numerical method for analyzing and designing complicated structures. One of the most widely accepted FEA software packages that are commonly used by engineers in different engineering fields is ANSYS. Many researchers discovered that the results obtained by ANSYS and experimental results were remarkably similar(Kandil, Heiza, & Soliman, 2014). (Kandil et al., 2014) measured the flexural capacity of reinforced concrete slabs experimentally and analytically by using ANSYS. The results showed that the theoretical and experimental results were slightly in agreement, especially up until the first crack load(Kandil et al., 2014). Similarly, (Gherbi et al., 2018) discovered that the flexural failure of an RC two-way slab modeled by Ansys and the failure load is extremely close to the results of the experimental approach. In 2019, (Emarah, 2019) compared the outcomes of ANSYS and Egyptian standing code (ESC) equations in terms of flexural behavior of RC slab strengthened with sheets of carbon fiber-reinforced polymer (CFRP). The results showed that there is a strong agreement between ANSYS and ESC. (Saifullah, I., Zaman, M. Uddin, S. M. K., Hossain, M. A and Rashid,M. H) investigated the flexural behavior of reinforced concrete beams by using experimental examination and finite element analysis (ANSYS,

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SAS 2005). This comparison study showed that the numerical modelling can be an excellent alternative of experimental examination with an acceptable variation of results.

(Erfan, Abd Elnaby, Badr, & El-sayed, 2021) studied the flexural performance of a High Strength Concrete (HSC) one-way slab reinforced with Baslat fiber reinforced polymer (BFRP) bars. The study included experimental testing and numerical analysis using Non-linear Finite Element (NLFEA) ANSYS. Good agreement was achieved between experimental results and NLFEA by about 88%-90% for first crack load, ultimate load, crack pattern and the deflection at ultimate load. For load carrying capacity, the agreement was achieved at about 89% with a standard deviation of 0.03 and a coefficient of variance about 0.001. Since concrete is a nonlinear material, it is challenging to accurately simulate its complicated stress-strain behavior. The SOLID65 element of the ANSYS software stands out because it can simulate concrete crushing in compression zones using a plasticity algorithm and smeared cracks in tension zones(Al-Smadi, Bhargava, Avci, & Elmorsi, 2012; Avci & Al-Smadi, 2019). The SOLID65 element has been extensively studied by various researchers and verified to be very successful in representing the behavior of reinforced concrete(Avci & Bhargava, 2019). The history of Shotcrete records that the first shotcrete one-way slab was tested at Lehigh University under the supervision of professor M.O. Fuller. This slab with a span (2.4 m) and thickness (82.6 mm) and this test continued for 14 years (from 1920 to 1934) and by 1922 the slab deflected by 50 mm and the reinforcing stressed to 160 Kn at completion. After the third year, there is no additional deflection measured (Yoggy, 2000).

Steel or synthetic fibers are now more commonly used in Shotcrete because they improve impact resistance, fracture toughness, and shear and flexural capacity at normal addition rates (0.3-1 percent volume fraction) ("ACI 506R-16,Guide to shotcrete ,reported by ACI commitee 506,Marc Jolin, Chair,"). (Shah, Gul, Naqash, Khan, & Rizwan, 2021) concluded that the addition of polypropylene fiber to Shotcrete up to 3 kg/m$^3$ could improve the compressive strength by nearly 20%, while flexural and tensile properties kept on increasing with a higher quantity of fibers. In addition to that, this study stated that Shotcrete has superior properties compared to concrete. (Jawheer, Mansoor, Al-Hadithi, & Hamad, 2021) studied the effect of waste plastic as fiber and coarse aggregate on Shotcrete. The results of compressive and flexural tests confirmed that when 0.5% of plastic fiber is used, the strength performance of Shotcrete concrete increases. After that, (Enad, Al-Hadithi, & Mansoor, 2022) discovered that increasing the waste plastic fiber percentage to 0.75 reduces the compressive strength of Shotcrete while increasing the splitting strength by 23-31%, 7-23%, and 6-38% for 7, 14, and 28 days, respectively. This study aims to study the possibility of using computer-based modelling in investigation the flexural behaviour of one-way reinforced concrete slab casted by using shotcrete contain waste plastic fibers and polypropylene fibers.

## 2. Materials

For preparation of shotcrete mixes in this research to obtain the mechanical properties, Ordinary Portland cement conforming to Iraqi specifications (IQS No.5/ 2019) was used. Fine and coarse aggregate with maximum size of 4.75mm and 10 mm respectively, were used and both are conforming to Iraqi specification (I.Q.S.) (No. 45/1984, 1984). The PET fibers with dimensions of (27 × 4 × 0.3) mm (length × width × depth) were produced by cutting waste plastic beverage bottles using shredding machine. whereas, the standard length of Polypropylene (PP) fibers is 60 mm. These fibers were cut into 30 mm length by a scissor. These two types are shown in Figure 1. Steel bars with diameter (8 mm) were used for reinforcement of RS slabs. The steel bar was tested according to ASTM A615 (Standard). Three steel bars Ø8mm were used at bottom of the slab as a longitudinal reinforcement and 4Ø8mm as a transverse reinforcement. Mixing proportions are illustrated in Table 1. This study involved the preparation of eleven mixes depending on the three percentages (0.35%, 0.7%, and 1%) including; reference plain concrete (FRC) and plain shotcrete mix (FRS); three mixes of waste plastic (PET) fiber reinforced shotcrete (WFRS-0.35, WFRS-0.7, WFRS-1); three mixes of macro synthetic (polypropylene) fiber reinforced shotcrete (PFRS-0.35, PFRS-0.7, PFRS-1); three mixes of hybrid fiber reinforced shotcrete (HFRS-0.35, HFRS-0.7, HFRS-1).

**Fig. 1 WPF and PPF**

**Table 1 Proportions of material used in shotcrete mixes**

| Group No. | Mix | Components Kg/m3 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | C. | S. | G. | W. | S.P. | Acc. | PET Fiber | Synthetic Fiber |
| **Group-1** | **FRC-0** | 497 | 880 | 739 | 183 | 3.1 | 22 | 0 | 0 |
| | **FRS-0** | 497 | 880 | 739 | 183 | 3.1 | 22 | 0 | 0 |
| **Group-2** | **WFRS-0.35** | 497 | 880 | 739 | 183 | 3.1 | 22 | 4.8 | 0 |
| | **WFRS-0.7** | 497 | 880 | 739 | 183 | 3.1 | 22 | 9.6 | 0 |
| | **WFRS-1** | 497 | 880 | 739 | 183 | 3.1 | 22 | 13.7 | 0 |
| **Group-3** | **PFRS-0.35** | 497 | 880 | 739 | 183 | 3.1 | 22 | 0 | 3.2 |
| | **PFRS-0.7** | 497 | 880 | 739 | 183 | 3.1 | 22 | 0 | 6.4 |
| | **PFRS-1** | 497 | 880 | 739 | 183 | 3.1 | 22 | 0 | 9.1 |
| **Group-4** | **HFRS-0.35** | 497 | 880 | 739 | 183 | 3.1 | 22 | 2.4 | 1.6 |
| | **HFRS-0.7** | 497 | 880 | 739 | 183 | 3.1 | 22 | 4.8 | 3.2 |
| | **HFRS-1** | 497 | 880 | 739 | 183 | 3.1 | 22 | 6.9 | 4.6 |

C= Cement, S= Sand, G= Gravel, W=Water, S. P= Superplasticizers, Acc.=Accelerator

## 3. Theoretical analysis

In this study, the theoretical flexural capacities (Mu) of reinforced concrete slabs were computed based on the equations provided by ("ACI Committee 318, “Building Code Requirements for Structural Concrete (ACI 318-19),”American Concrete Institute, Farmington Hills, MI 48331, 2019.," ; Ammar Ahmed Hammadi, 2012; Madan, Munuswamy, Joanna, Gurupatham, & Roy, 2022). The predicted failure mode can be determined by comparing the reinforcement ratio in Equation (1) to the balanced reinforcement ratio in Equation (2).

$$\rho = \frac{A_s}{bd} \qquad ... (1)$$

where $A_s$ is the area of steel rods, $b$ is the width of the cross-section, and $d$ is the distance from the extreme compression fiber to the centroid of the steel rods.

$$\rho_b = 0.85\beta_1 \frac{f'_c}{f_y}\left(\frac{600}{600+f_y}\right) \qquad ... (2)$$

where $f'_c$ is the specified compressive strength of concrete, $f_y$ is the yield tensile stress of steel bars. The factor $\beta_1$ can be calculated using Equation (3).

$$\beta_1 = 0.85 - 0.05\left(\frac{f'_c - 28}{7}\right) \qquad .. (3)$$

If ($\rho < \rho_b$), then the condition of failure is due to tension. From the above conditions, all of the tested concrete slabs reinforced failed due to tension failure. Moment of resistance ($M$) can be calculated using Equation (4)

$$M_n = A_s f_y \left(d - \frac{a}{2}\right) \quad .....(4)$$

Where a is the effective depth and calculated by using equation (5).

$$a = \frac{A_s f_y}{0.85 * f_c' * b} \quad .... (5)$$

from structural analysis of simply supported slab with two-point load, the maximum moment can be calculated by using equation (6).

$$M_{\max} = \frac{3PL}{16} \quad ....(6)$$

## 4. Finite Element Analysis (FEA)

ANSYS v15 FE program was used in this study. The modeling of the one-way slab started by choosing the SOLID-65 for modeling the concrete. This solid element has eight nodes and three degrees of freedom for each node. Link 180, with two nodes and three degrees of freedom for each node, was used to model steel reinforcement rod. A three-dimensional brick element (SOLID 185) was used for modeling the supports. This element has eight nodes and three degrees of freedom for each node.

The input data that was required for the modeling of SOLID 65 was as follows: elastic modulus = $4700\sqrt{f_c'}$), tensile strength of is specified as 10% of its compressive strength, poison's ratio = 0.2, open shear transfer coefficient = 0.1, closed shear transfer coefficient = 0.9. The data for modelling steel bars is as follows: yield stress = 491 MPa, modulus of elasticity = 200000 MPa, and poison's ratio = 0.3. Table 1 and Figure 3 shows the comparison between results of numerical analysis and experimental examination of one-way reinforced concrete slab specimens.

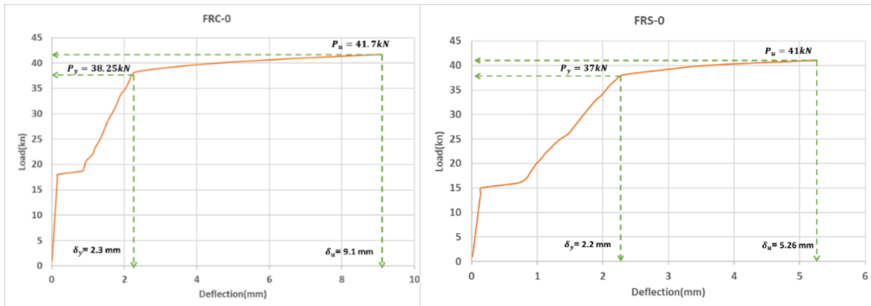
## 5. Results and Discussions

Compressive strength at 28 days was obtained by casting a shotcrete panel for each mix then the cores was extracted from theses panels to conduct a compressive test in accordance with ASTM C1604/C1604M.

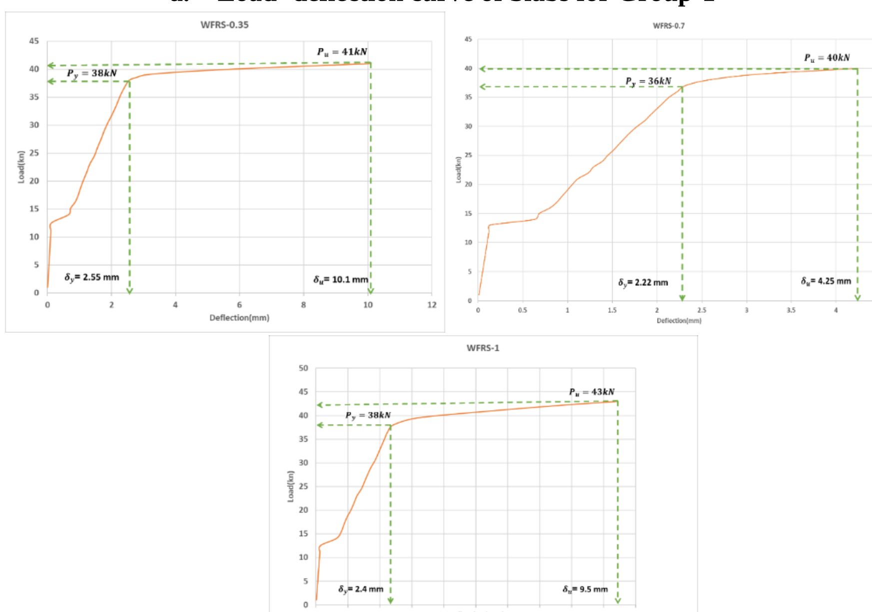
Table 2 and Figure 2 shows the load and deflection at yield and ultimate point that obtained by modelling and analyzing of one-way slab by using Ansys v.15. It is clear from results that the polypropylene fiber has a good effect on the compressive strength that increased by about 8.2%, 2.8%, and 3.9% with a percentage of 0.35%, 0.7%, and 1%, respectively. this effect contributed in improvement of flexural behavior of shotcrete slab in term of ultimate load by about 7.4%, 4.6%, and 1.5% with a percentage of 0.35%, 0.7%, and 1%, respectively.

**Table 2 loads and deflections at yield and ultimate point**

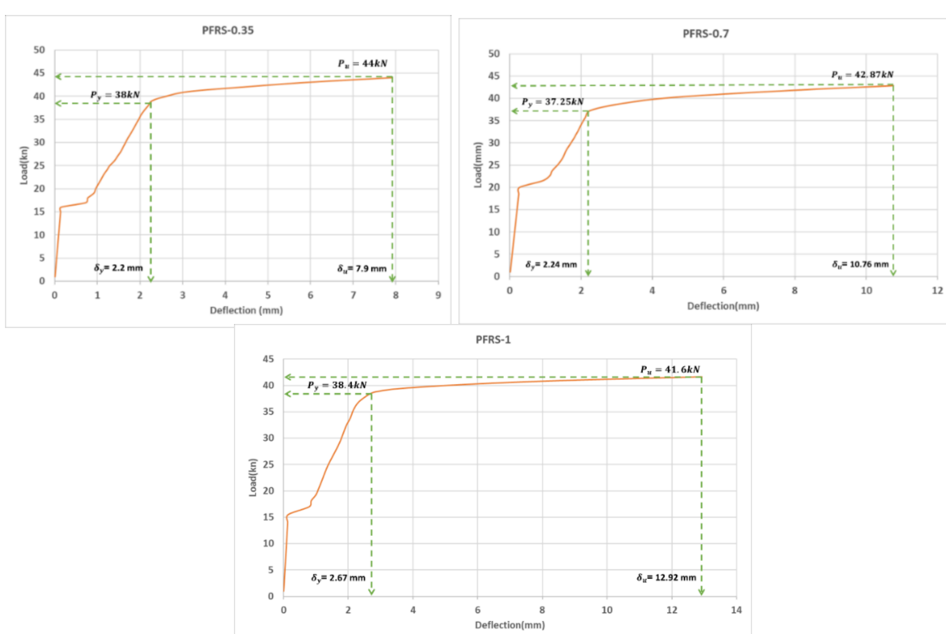
| Group | Mix Symbol | $f_c'$ | At yield point | | At Ultimate point | |
|---|---|---|---|---|---|---|
| | | | $P_y$ | $\delta_y$ | $P_u$ | $\delta_u$ |
| G-1 | **FRC-0** | **41** | 38.25 | 2.3 | 41.7 | 9.1 |
| | **FRS-0** | **34.53** | 37 | 2.2 | 41 | 5.26 |
| G-2 | **WFRS-0.35** | **29.37** | 38 | 2.55 | 41 | 10.1 |
| | **WFRS-0.7** | **30.27** | 36 | 2.22 | 40 | 4.25 |
| | **WFRS-1** | **27.31** | 38 | 2.4 | 43 | 9.5 |
| G-3 | **PFRS-0.35** | **37.37** | 38 | 2.2 | 44 | 7.9 |
| | **PFRS-0.7** | **35.48** | 37.25 | 2.24 | 42.87 | 10.76 |
| | **PFRS-1** | **35.89** | 38.4 | 2.67 | 41.6 | 12.92 |
| G-4 | **HFRS-0.35** | **29.14** | 37 | 2.33 | 42 | 10.4 |
| | **HFRS-0.7** | **32.2** | 37.25 | 2.34 | 39.75 | 6.06 |
| | **HFRS-1** | **34.03** | 38.4 | 2.9 | 41.38 | 11.52 |



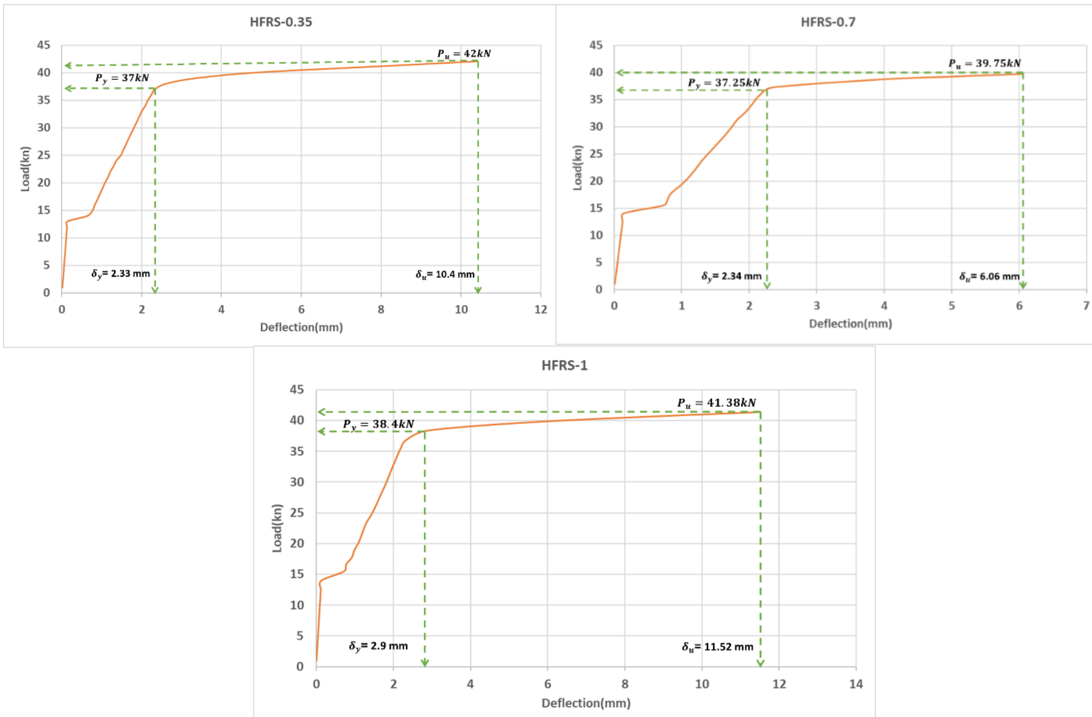

**a. Load- deflection curve of Slabs for Group-1**




**b. Load- deflection curve of Slabs for Group-2**




**c. Load- deflection curve of Slabs for Group-3**




**d. load- deflection curve of Slabs for Group-4**

**Fig. 2 Load deflection curves of numerical (ANSYS) modelling slabs**

## 5.1. Comparison of Analytical with Numerical Analysis

The ANSYS FE program results compared to the results of theoretical analysis of ACI-19. Table 3 and Figure 3 show a comparison between ultimate load obtained from the ANSYS model and ACI code equation.

**Table 3 Ansys and theoretical (ACI) results**

| Group | Mix Symbol | Ansys $P_u$ | Theoretical $P_u$ | $P_{u-\_Ansys}/P_{u-Theo.}$ |
|---|---|---|---|---|
| **G-1** | **FRC-0** | 41.72 | 43.33 | 0.963 |
| | **FRS-0** | 41 | 43.01 | 0.953 |
| **G-2** | **WFRS-0.35** | 41 | 42.67 | 0.961 |
| | **WFRS-0.7** | 40 | 42.73 | 0.936 |
| | **WFRS-1** | 42.7 | 42.48 | 1.005 |
| **G-3** | **PFRS-0.35** | 44 | 43.17 | 1.019 |
| | **PFRS-0.7** | 42.87 | 43.07 | 0.995 |
| | **PFRS-1** | 41 | 43.09 | 0.951 |
| **G-4** | **HFRS-0.35** | 42 | 42.64 | 0.985 |
| | **HFRS-0.7** | 39.75 | 42.87 | 0.927 |
| | **HFRS-1** | 41.38 | 42.98 | 0.963 |
| **Mean Value** | | | | **0.97** |
| **Variance** | | | | **0.00076** |
| **Standard Deviation** | | | | **0.027** |

The results for both approaches showed a good agreement in terms of ultimate load with the average of ultimate load $P_{u\_Ansys}/P_{u\_ACI.}$,coefficient of variance, and standard deviation equal to 0.97, 0.00076, and 0.027 respectively. According to these results, the ANSYS FE model can be used to investigate the ultimate load of other combinations of one-way slabs with the same assumptions.

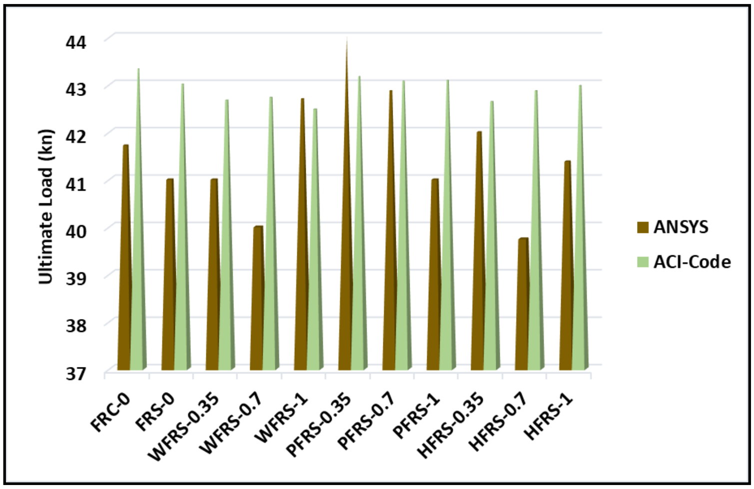
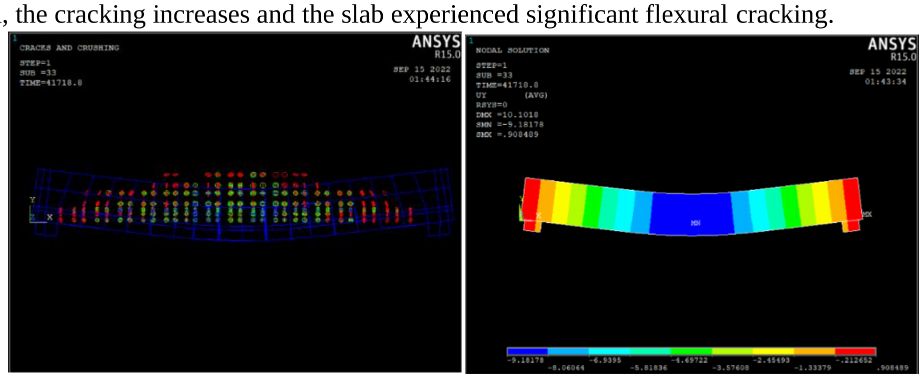


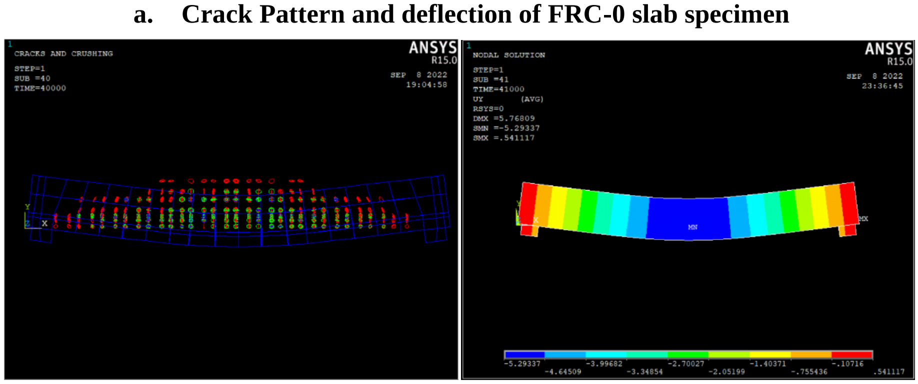

**Fig. 3 Effect of fiber on the Air Voids.**

## 5.2. Deflection and Crack Pattern

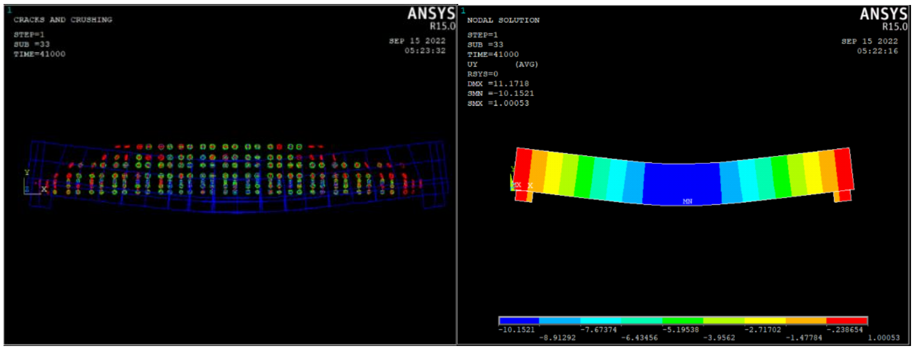
Figure 4 displays the deflection of the all-slabs model as estimated using the ANSYS FE software. It is clear from the specimen's model that the highest value of deflections was recorded at the middle of the slab span and it is gradually decreased towards the supports. All deflection values are illustrated in Table 3. The crack pattern was recorded by ANSYS software at each step of loading. The locations of concrete cracking and crushing are displayed as a circle. Octahedron shape refer to crushing, whereas cracking is represented by outline in the plane of the cracks. The first, second, and third cracks at an integration point are presented by a red, green, and blue circle outline, respectively. Under various loading conditions, the following crack patterns can be seen. As more stresses are applied to the slab, subsequent cracking occurs in the non-linear region of the response. in the constant moment region, the cracking increases and the slab experienced significant flexural cracking.



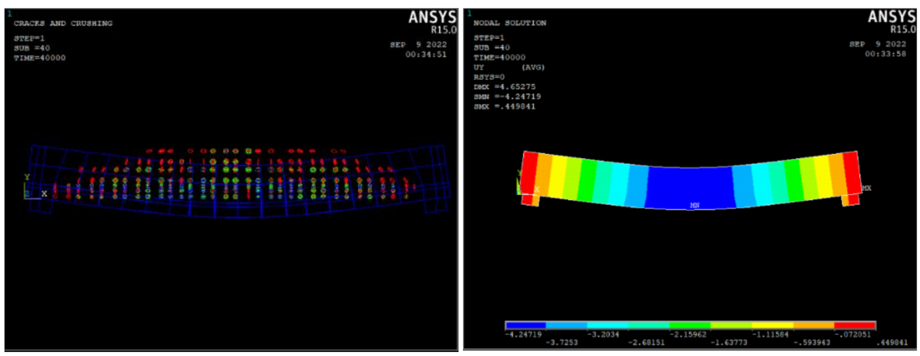

**a. Crack Pattern and deflection of FRC-0 slab specimen**



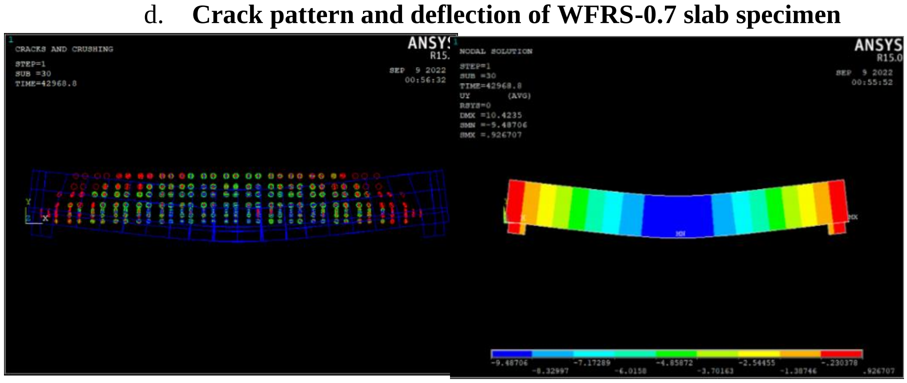

**b. Crack pattern and deflection of FRS-0 slab specimen**



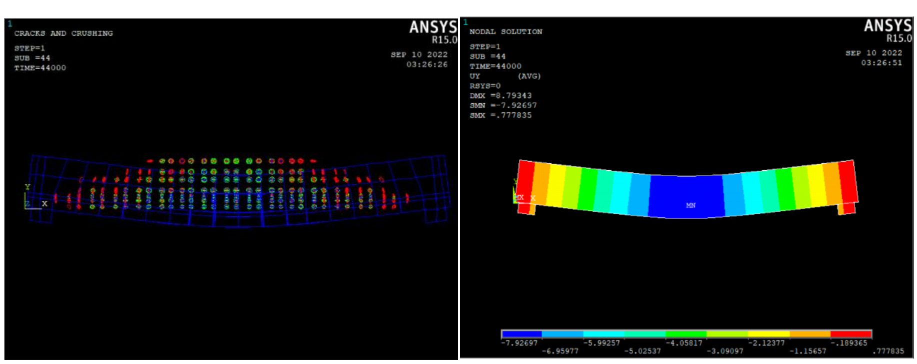
c. **Crack pattern and deflection of WFRS-0.35 slab specimen**



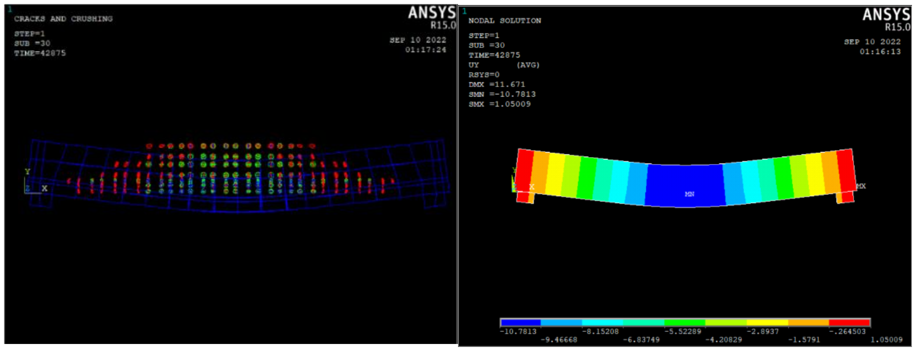
d. **Crack pattern and deflection of WFRS-0.7 slab specimen**



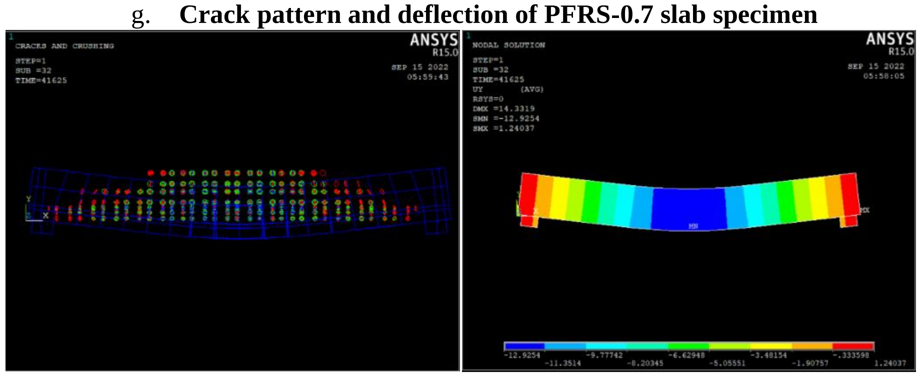
e. **Crack pattern and deflection of WFRS-1 slab specimen**



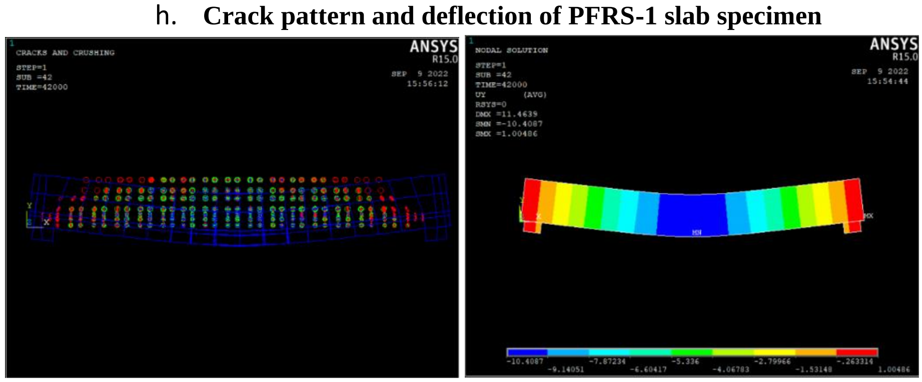
f. **Crack pattern and deflection of PFRS-0.35 slab specimen**



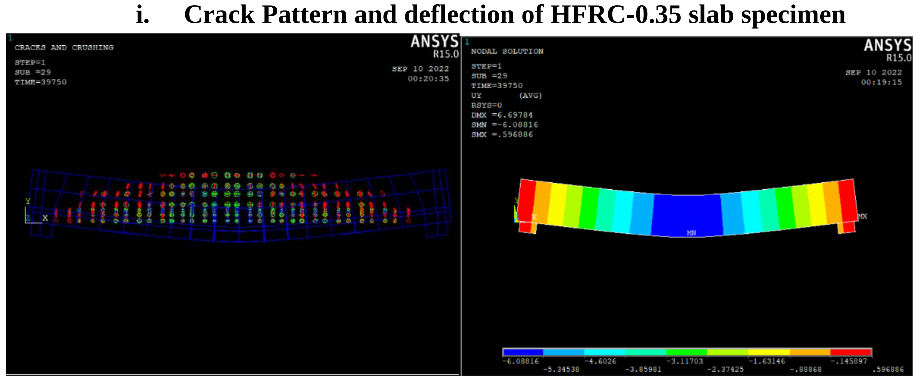

g. **Crack pattern and deflection of PFRS-0.7 slab specimen**



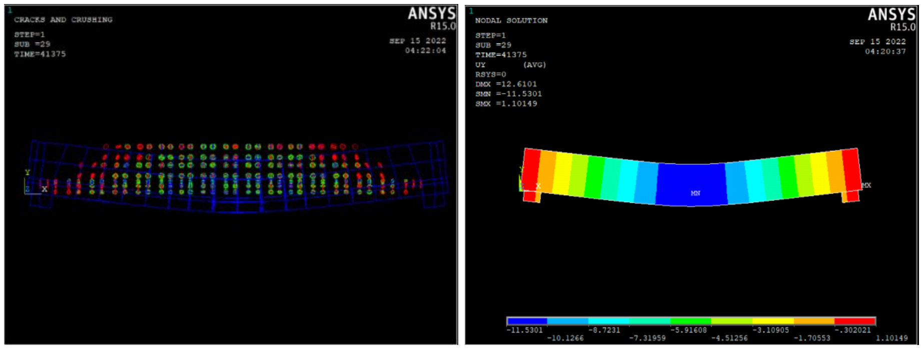

h. **Crack pattern and deflection of PFRS-1 slab specimen**




**i. Crack Pattern and deflection of HFRC-0.35 slab specimen**




**j. Crack Pattern and deflection of HFRS-0.7 slab specimen**




k. **Crack pattern and deflection of HFRS-1 slab specimen**

**Figure 4 Cracks pattern and deflection of slabs by ANSYS program**

## 6. Conclusions

From this research, the following conclusions and observations can be made based on experimental examination, theoretical analysis, and numerical analysis of reinforced concrete slabs casted by shotcrete contain plastic fibers.

1- Polypropylene fibers improved flexural behavior of shotcrete slab in term of ultimate load by about 7.4%, 4.6%, and 1.5% with a percentage of 0.35%, 0.7%, and 1%, respectively

2- The analytical equations given by ACI318-19 for calculating the moment of resistance can be used for the design of reinforced shotcrete slabs contain plastic fiber.

3- The results of finite element analysis (ANSYS v15) showed good agreement with theoretical and experimental results in terms of ultimate load.

4- The variance of ultimate load values for ANSYS values from theoretical values are equal to 0.00076.

5- Hence, ANSYS v15 software can be used for the analysis of reinforced concrete slabs casted by shotcrete contain waste plastic fibers and polypropylene fibers.

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