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EXPERIMENTALLY AND NUMERICALLY INVESTIGATION OF LOCAL METAKAOLIN EFFECT ON BEHAVIOR OF REINFORCED CONCRETE BEAMS

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ABSTRACT

Recently, there was an energy crisis in Egypt, due to many energy-consuming industries, such as cement industry, as it is an energy-intensive process. Therefore, efforts must be made to find alternatives to cement industry. Cementitious materials play an important role in production of concrete. In addition to this, continuous increase in the cost of cement in addition to air pollution that occurs during cement production. This prompted researchers to use other pozzolanic materials, such as clay and kaolin, as alternatives to cement. In this study, local kaolin was thermally treated to produce (metakaolin). The durability was experimentally examined for different cement contents, using different percentages of metakaolin as a substitute for cement weight. Many tests have been performed to achieve to the optimum percentage . Concrete beams were cast using the control mix and the ideal mix and the results were compared with those obtained using the specified Ansys element

KEYWORDS: Metakaolin, Concrete Beams , Ansys, Mechanical Tests, Pozzolanic Materials , Cementing materials.

دراسة تأثير الميتاكاولين المحلي على سلوك الكمرات الخرسانية المسلحة معملياً وعددياً

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الملخص

في الآونة الأخيرة حدثت أزمة طاقة في مصر بسبب كثرة الصناعات المستهلكة للطاقة، مثل صناعة الأسمنت ، فهي عملية كثيفة الاستهلاك للطاقة. ولذلك يجب بذل الجهود لإيجاد بدائل لصناعة الأسمنت. تلعب المواد الأسمنتية دورًا مهمًا في إنتاج الخرسانة. بالإضافة إلى ذلك الارتفاع المستمر في تكلفة الأسمنت ، بخلاف تلوث الهواء الذي يحدث أثناء إنتاج الأسمنت. وهذا ما دفع العديد من الباحثين إلى استخدام مواد بوزولانية أخرى مثل الطين والكاولين، كبدائل للأسمنت. في هذه الدراسة تم معالجة الكاولين المحلي

حرارياً لإنتاج (الميتاكاولين). تم فحص المتانة عملياً لمحتويات مختلفة من الأسمنت باستخدام نسب مختلفة من الميتاكاولين كبديل لوزن الأسمنت. وقد تم إجراء العديد من الاختبارات للوصول إلى النسبة المثلى. تم صب العتبات الخرسانية باستخدام خلطة التحكم والخلطة المثالية وتمت مقارنة النتائج مع تلك التي تم الحصول عليها باستخدام طريقة العناصر المحددة برنامج Ansys .

الكلمات المفتاحية : ميتاكاولين، كمرات خرسانية، الانسيز، الاختبارات الميكانيكية، المواد البوزولانية، المواد الاسمنتية .

1. INTRODUCTION

High performance and strength concrete has recently become required for the construction industry, and many researches have studied various criteria for using metakaolin as a supplement to cement as a compound, such factors are (fineness ,mineral composition, workability, strengths of cement mortars and concrete, permeability, resistance to chemical attack, durability etc.)

Many researches have been discussed the uses of Metakaolin as a partial replacement by cement and improving compressive strength of concrete mixture. Also many researchers made studies on the effect of using Metakaolin and showed that the compressive strength and workability are improved. Other studies were on porosity, water permeability, and the chloride permeability and evaluated against a reference mixture. They found that inclusion of Metakaolin improve durability, but no enhancement on water permeability of the mixture. Another research discussed using of Metakaolin 25 % as cement replacement in six types of concrete from immediate release concrete to self-compacting concrete and low to high-performance concrete mixture . They found that permeability and penetration of chloride were reduced, and strength was increased in mixture also performance of concrete mixture, using Metakaolin replacement by weight of the cement is improved. It will be at a level of 20% [1-8].

Many research have been studying the structure behavior in reinforced concrete as a partial substitute for cement mixtures with different percentages, some researches from (5% to 35%) and others from (0% to 15%). There are researches show that the optimum behavior of Metakaolin percentage was 20% and another was 15%, then decreases below these percentages. There are some studies that made a mixture of Metakaolin and another addition, such as, Limestone and Fly Ash. They also made these studies of Metakaolin partial replacement with cement in different percentages. Also, they studied the mechanical properties of reinforced concrete and test mixture at age of (7,28) days and sets the value of compressive strength and flexural strength while another research gives better results at 7,28,90 and 180 days such as water penetration, sorptivity, and electrical resistivity. All of the researches confirmed that the use of Metakaolin gives high resistance and durability [9-14].

2. Materials and Methods

2.1. Details Models

In this research, different percentages of metakaolin were used as a partial substitute by weight for cement with values of cement with value (0, 5, 10, 15, 20, and 25%). In addition to that, two cement content were used which are 250 and 350 kg /m3. Fresh concrete mixes properties were determined by slump test while hardened concrete mixes properties were determined were compressive strength, indirect tensile strength, and water sorptivity tests.

- The experimental program was divided into five groups: -

1. In the 1st group, two different concrete mixtures with a cement content of 0% metakaolin were poured. 12 cubes (150*150*150 mm) were prepared to conduct compressive strength tests at 7 and 28 days of age as per ASTM C 39. While the fresh state measurements and workability of concrete mixtures is measured by means of the standardized slump test as outlined by ASTM C-143, then the control mix was chosen according to its workability and strength.
2. In the 2nd group, five concrete mixes, different in cement content, with (5, 10, 15, 20, 25) % Metakaolin were cast. There were 60 cubes (150*150*150 mm) are prepared for compressive strength test at 7 and 28 days of age according to ASTM C 39. While the fresh state measurements and workability of concrete mixtures is measured by means of the standardized slump test as outlined by ASTM C-143, then the control mix was chosen according to its workability and strength.
3. In the 3rd group, six concrete mixes, different in cement content, with (0, 5, 10, 15, 20, and 25%) Metakaolin were cast. There were 36 cubes (100*100*100 mm) prepared to perform an indirect tensile strength test at age of 28 days.
4. In the 4th group, six concrete mixes, different in cement content, with (0, 5, 10, 15, 20, and 25%) Metakaolin were cast. There were 12 cubes (70*70*30 mm3) prepared to perform the sorptivity test after 28 days.
5. Finally, in the 5th group, two concrete mixes, different in cement content, with (0 and 15 %) Metakaolin were cast. There were four beams with dimensions (120*500*2000 mm3) were prepared and tested after 28 days.

2.2. Used Materials

Cement used in this study is type I , which have chemical and mechanical properties as listed in Table 1.

Table 1: Components and properties of the used cement.

Component	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	L.O.I
Percentage (%)	20.13	5.32	3.61	61.63	2.39	2.87	0.37	0.13	1.96

Property	Result
Compressive strength (3-days)	156.6 kg/cm^2
Compressive strength (7-days)	195.7 kg/cm^2

2.2.1. Metakaolin

- Metakaolin is prepared by hydroxylation of kaolin at 700°C. This temperature leads to chemical loss of water, collapse of the crystalline structure and thus transformation of the phase into amorphous with high reaction capacity called metakaolin.
- Metakaolin can be used as a concrete component, replacing part of the cement content because it has pozzolanic properties. It has been used as a partial cement replacement material in mortars and concrete and has been widely studied in recent years.

Table 2: Compare between chemical composition & physical properties (Kaolin – Metakaolin).

		Kaolin	Metakaolin
Chemical analysis (%)	SiO_2	51.25	52.72
	Al_2O_3	40.70	41.18
	Fe_2O_3	1.18	1.74
	CaO	0.20	0.32
	MgO	0.10	0.28
	Na_2O	0.06	0.16
	K_2O	0.18	0.20
	L.O.I.	10.7	1.33
Physical Properties	Color	White	Off White
	Specific Gravity	2.60	2.30

2.2.2 Fine Aggregate

Available clean natural sand with particle size smaller than 0.5 mm, specific gravity 2.58 g/cm^3 and fineness modulus 2.25 was used as fine aggregate.

2.2.3 Coarse Aggregate

Sieve analysis of the coarse aggregate was carried out, but clean crushed dolomite with a maximum size of 12 mm and a specific gravity of 2.65 g/cm^3 was used as the coarse aggregate.

2.2.4. Water

The water used in the mixture design was potable. The source of this water was the water supply network system. The water used must be free of organic materials and suspended solids that may affect the properties of concrete in its fresh and hardened state.

2.2.5. Super Plasticizer

ARACO SP 122 was used as a superplasticizer for a highly effective water reducing agent and to produce high quality concrete, the experimental dosage 2.5% by weight of cement. The properties of super plasticizer are shown in **Table 3**.

Table 3: Properties of used super plasticizer

Density	1.2±0.005 KG\ L (ASTM C494)
Colour	Black Liquid
Recommended Dosage	0.5-2.7 % by weight of cement

Table 4 : Weight of Mixtures components (kg) per 1 m^3 (Cc = 350KG/ 1m^3)

MIX	MK	CEMENT	AGGREGATE		WATER	SP
			COARSE			
MIX 0	0	350	2368	1032	175	8.75
MIX1	17.5	332.5	2368	1032	175	8.75
MIX2	35	315	2368	1032	175	8.75
MIX3	52.5	297.5	2368	1032	175	8.75
MIX4	70	280	2368	1032	175	8.75
MIX5	87.5	262.5	2368	1032	175	8.75

Table 5 : Weight of Mixtures components (kg) per 1 m^3 (Cc = 250KG/ 1m^3)

MIX	MK	CEMENT	AGGREGATE		WATER	SP
			COARSE	FINE		
MIX 0	0	250	2368	1032	125	6.25
MIX1	12.5	237.5	2368	1032	125	6.25
MIX2	25	225	2368	1032	125	6.25
MIX3	37.5	212.5	2368	1032	125	6.25
MIX4	50	200	2368	1032	125	6.25
MIX5	62.5	187.5	2368	1032	125	6.25

2.3 Equipment

2.3.1. The standard sieves

The sieves used for particle size distribution were carried out using sieves of mesh opening. The Sieves used for fine aggregate were as follows (9.5, 4.75, 2.36, 1.18, 0.60, 0.30, 0.15, 0.075 mm) while Sieves used for coarse aggregate were as follows (37.5, 20, 14, 10, 5, 2.36 mm).

2.3.2 Mixer

To create concrete, cement, water, and materials such as sand or gravel are mixed uniformly in a concrete mixer. The rotating drum in a concrete mixer is usually used to mix ingredients. Portable concrete mixers are frequently used on small-scale projects so that the concrete can be prepared on the job site, giving workers plenty of time to use it before it hardens. Concrete can be mixed by hand as an alternative to machines

2.4 Testing Methods

2.4.1 Slump cone

A cone has a height of 30 cm, a bottom diameter of 20 cm, and a top diameter of 10 cm. The tamping rod is made of steel, 16 mm in diameter, 60 cm long, and rounded at one end.

2.4.2 Standard Cube test concrete

Cubes having a dimension of (15 cm*15 cm*15cm) were used for the compressive strength test.

2.4.3 Oven

The oven was used for drying the sample at a temperature of 70°Cfor 4 days and then left to cool for 24 hours to prepare the samples for the sorptivity test.

2.4.4 Curing tank

Samples were disassembled and treated in water for the day of testing at 20°C.

2.4.5 Universal testing machine

A universal testing machine of 500 KN capacity in tension & 2000 KN capacity in compression was used for the mechanical characterization of investigated samples.

2.4.6 Strain rate calculation

It is a tool that is used for measuring the strain on concrete.

2.5 Experimental Procedure

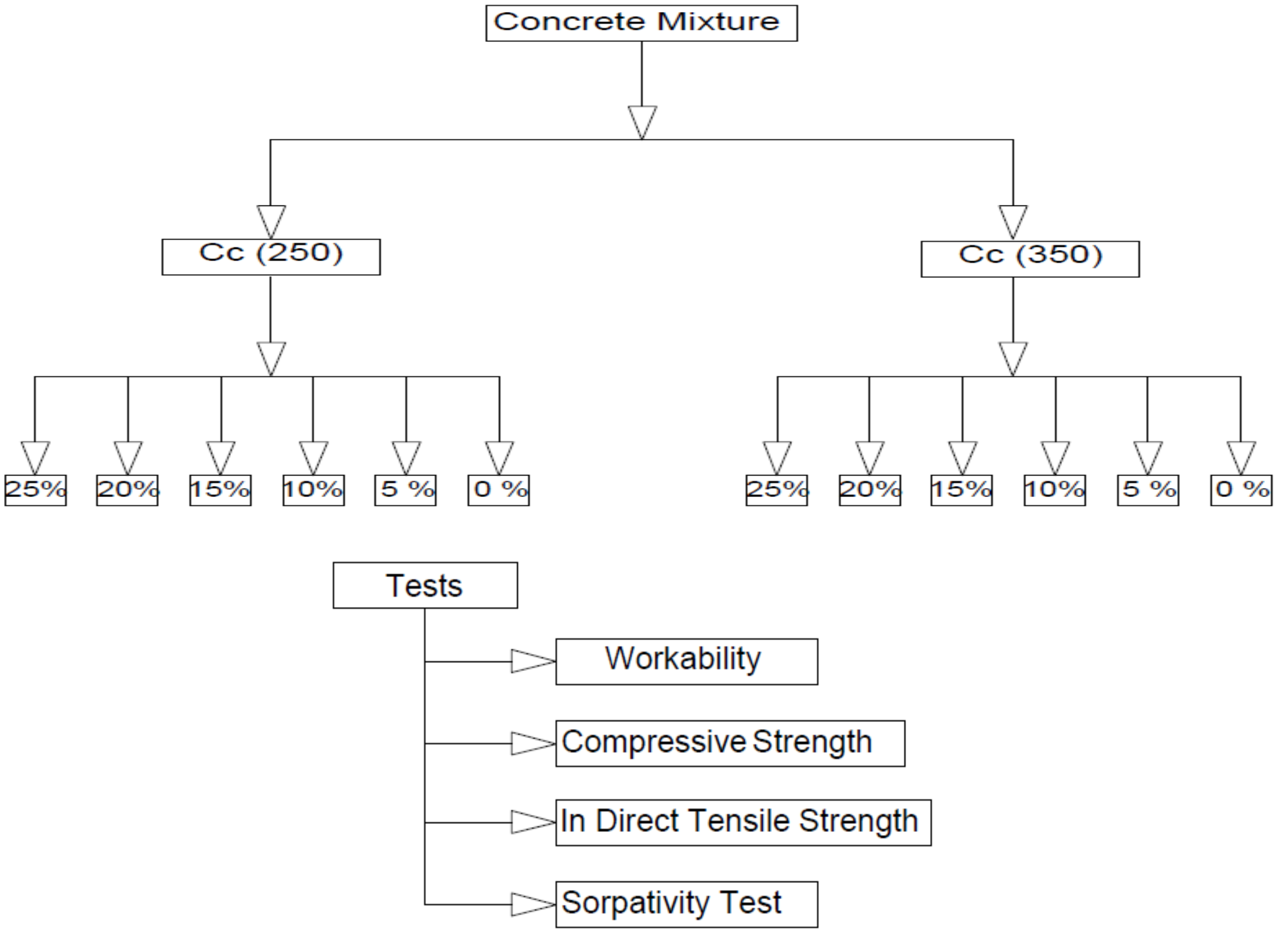

Figure 1: Experimental Procedure

3- Mixture

A total of 10 series of mixtures were prepared in the laboratory. The control mixture was made from natural aggregate, cement and water. Metakaolin concrete mixtures were manufactured using commercial metakaolin and an appropriate amount of superplasticizer.

- The mixtures were prepared with metakaolin replacement ratios of 5%, 10%, 15%, 20% and 25% by weight of cement in the mixture. The water to cement ratio for all was 0.55. Aggregate mixtures consist of a mixture of crushed dolomite and fine sand
- Super Plasticizer 2.5 % by weight of cement

All mixtures were prepared by mixing coarse aggregate, fine aggregate and cement in a laboratory concrete mixer.

4. Effect of Metakaolin Ration on Behavior of Reinforced Concrete Beams Experimentally and Numerically Program

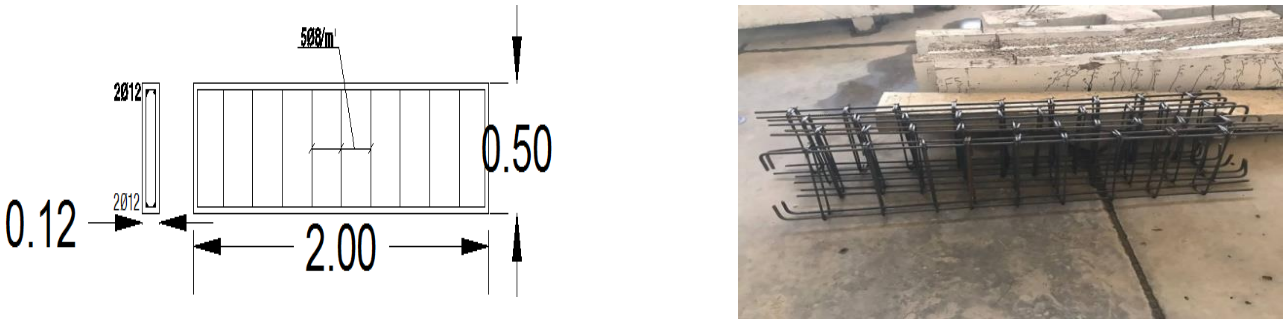

Figure 2: Model with Dimension

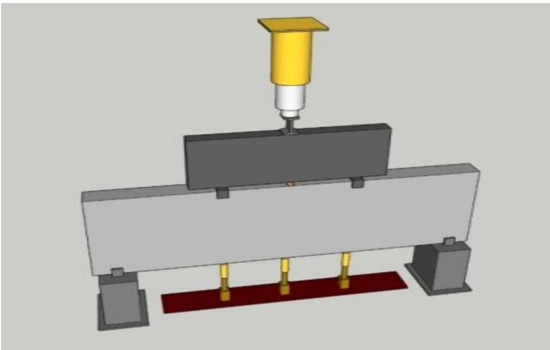

Figure 3: Model in 3D

Figure 4: Preparing Model for Test

4.1 Numerical Programme

4.1.1 Description of the models

4.1.1.1 Concrete

- The behavior of concrete is different in compression and tension as shown in **Table 6**

Table 6: Properties of Concrete Material

Properties	Value
Density	2500 kg/cm^3
Modulus of Elasticity	(Ec =4400 (fcu)^½) = 27500 Mpa
Poisson's Ratio	0.2

4.1.1.2. Steel

The steel reinforcement which used in RC beam is grade of 500 DWR. In finite element models, steel has been defined as elastic-plastic material and its behavior is symmetric in compression and tension behavior.

- Poisson's ratio value equal 0.3.

5. Shape of Element

-In finite element modeling of concrete beams in the Ansys Solid 65 program, a concrete model is used that has three degrees of freedom at each node.
The purpose of using solid 65 is because of its cracks in three orthogonal directions, plastic deformation and crushing.
-For modeling, steel reinforcement was used in the beams, and a 180 spar element connection with three degrees of freedom at each node.
- The purpose of using the 180 bond is a three-dimensional tape that is useful in various engineering applications.
The element is uniaxial tension compression.
- An element has three degrees of freedom at each nodal translation in the nodal directions x, y and z.
- It is a hinge element; The curvature of the element is not taken into account.

6. Results & Discussions

6.1. Workability test

The following table shows the results of the workability test for fresh concrete with partial replacement of cement with metakaolin in different percentages ranging from 5% to 25% in increments of 5% .

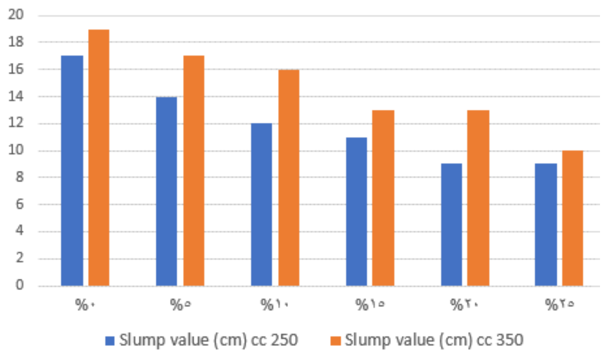

Figure 5 : Results of Workability Test

Table 7: Results of Workability test

	CC 250	CC 350
MIX	Slump Value (cm)	
0	17	19
5	14	17
10	12	16
15	11	13
20	9	13
25	9	10

- The experimental result shows that when Metakaolin in concrete increases workability decreases.

6.2. Compressive Strength

The following table shows the results of the compressive strength test conducted on hardened concrete with partial replacement of cement with metakaolin at a range of (0 - 25%) metakaolin at 7 and 28 days of age.

- Results show that the compressive strength increases as curing time increases.

Table 8: Results of compressive strength test (N/mm^2)

	CC 250		CC 350	
MIX	7 days	28 days	7 days	28 days
0	22.1	34.5	27.7	39.5
5	28.3	39.3	29.6	39.6
10	29.1	40.2	32.6	43.6
15	30.2	43.2	34.7	46.3
20	24	32.8	25.1	39.1
25	19.1	25.9	23.6	32.8

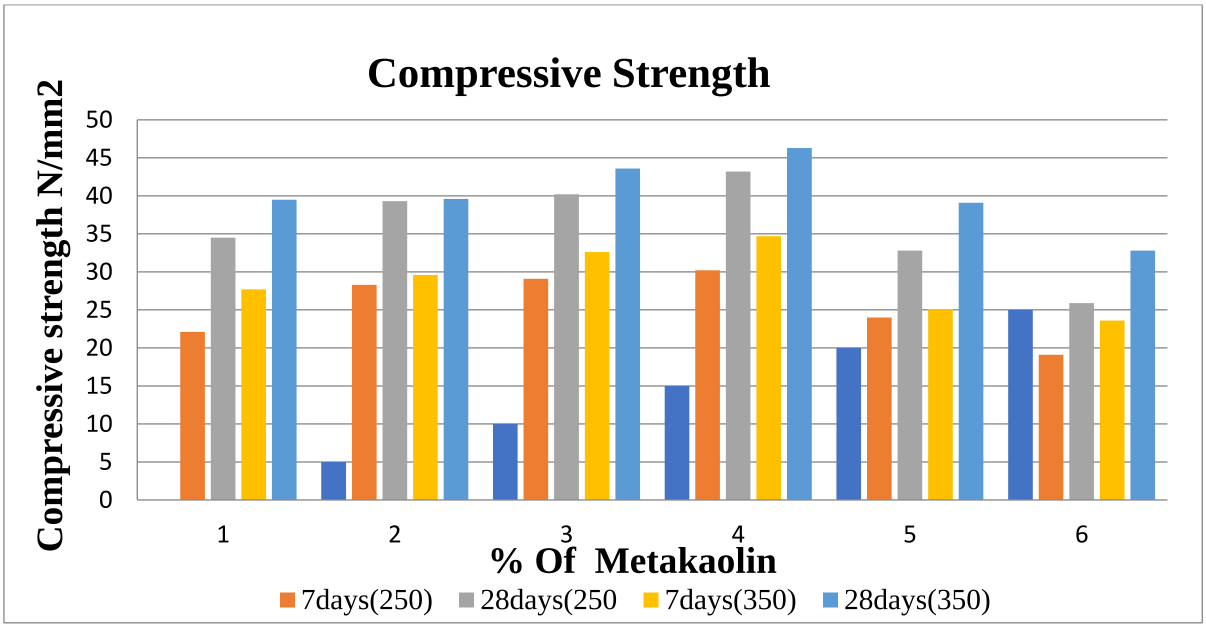

Figure 6: Compressive Strength

- Experimental results showed that the value of compressive strength increased for samples containing different percentages of metakaolin as a cement replacement material compared to the control mixture. Compressive strength test results are performed at 7 and 28 days of age.

- It was found that the use of a percentage of cement with Metakaolin leads to early resistance, and that the use of Metakaolin as an alternative to cement weight gives an increase in resistance at a rate of 25.2% to 36.7% in cement content 250 Kg/m^3, and give an increase in resistance at a rate of 17. 2% to 25.3% in cement content 350 Kg/m^3.
- The results show that the maximum strength was achieved at 15% replacement for all test ages and decreases below this percentage .

6.3. In Direct Tensile Strength

- The following table shows the results of the direct tensile strength test conducted on hardened concrete with partial replacement of cement with metakaolin at a range of (0 - 25%) metakaolin at the age of 28 days
- The results showed that the behavior of metakaolin in concrete is significantly superior to concrete that uses only Portland cement as a binder in concrete .

Table 9: Results of tensile strength

	CC 250	CC 350
MIX	Tensile Strength (N/mm^2)	Tensile Strength (N/mm^2)
0	2.52	2.74
5	2.62	2.93
10	2.71	3.12
15	2.81	3.25
20	2.45	2.77
25	1.89	2.39

- It was found that the use of Metakaolin as an alternative to cement weight gives an increase in tensile strength with percentage 11.5 % in cement content 250 Kg/m^3, and give an increase with percentage 18.6 % in cement content 350 Kg/m^3.
- The results showed that maximum strength was obtained at 15% replacement of cement content.

6.4. Sorptivity Test

Water sorptivity (capillary water absorption test) was determined for the control mix and 15% Metakaolin replacement of cement at age of 28 days as shown in figures for the two cement content.

For each mix, the volume of water penetrated per unit area in mm (i) was plotted versus the

Equation: $S = i/\sqrt{time}$

S = sorptivity in (mm/min$^{0.5}$) i = volume of water penetrated per unit area in (mm)

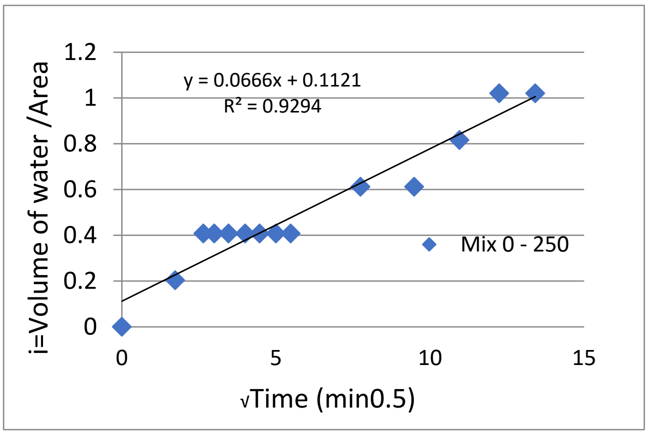

Figure 7: Result of Sorptivity test for mix (0 –

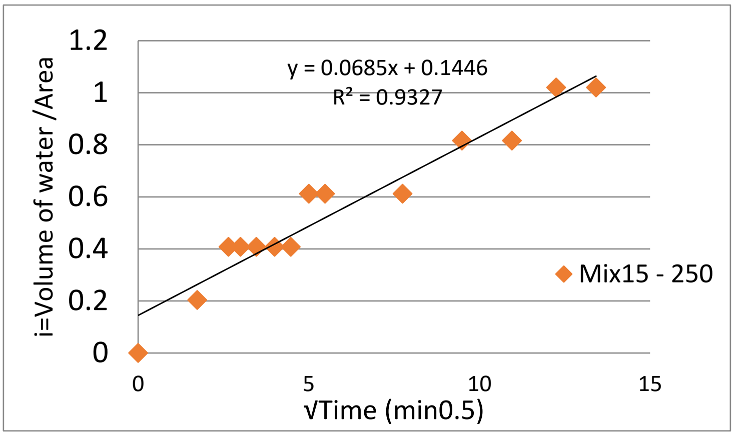

Figure 8: Result of Sorptivity test for mix (15 – 250)

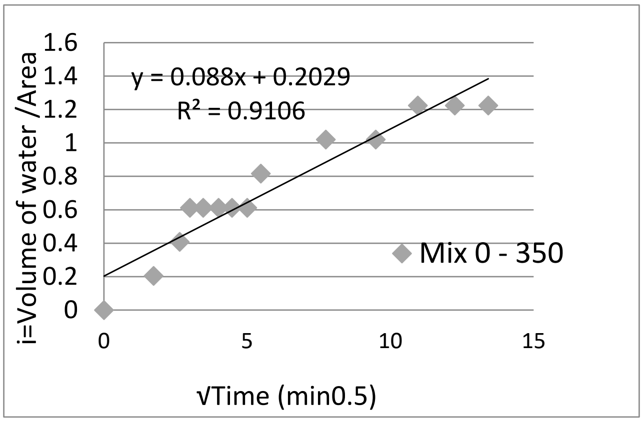

Figure 9: Result of Sorptivity test for mix (0 – 350)

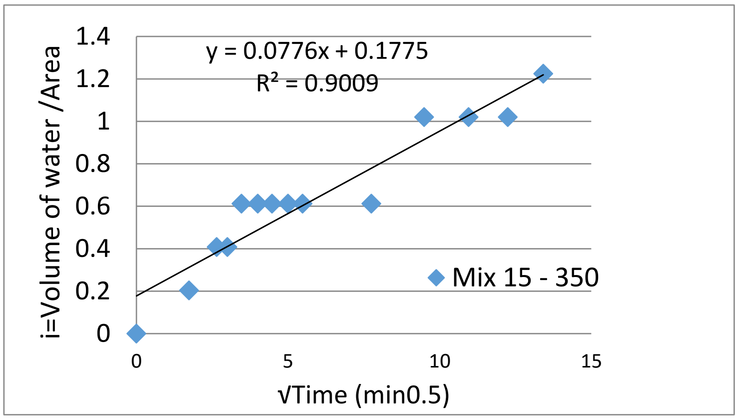

Figure 10: Result of Sorptivity test for mix (15 – 350)

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6.5 Analysis of beams models

- **Table 10** shows crack load which is obtained in laboratory tests and by analysis by Ansys for beams.

Table 11 compares between Failure Load for Models Experimentally and by Ansys.

Table 10 : Show the Crack load Experimentally and by Ansys

Mix	Crack load Experimentally (Ton)	Crack load from Ansys (Ton)
0-250	9.5	13.5
15-250	10.8	16.3
0-350	11.3	16.6
15-350	13.5	18.4

Table11 : Compare between Failure Load for Models Experimentally and by Ansys

Mix	Experimentally (Ton)	Ansys (Ton)	Ratio between experimentally & theoretical failure load (%)
0-250	21.4	24.4	87.7
15-250	22.8	25.8	88.4
0-350	22.8	25.2	90.5
15-350	24	27	88.9

- Experimental results show that failure load has increased for models with 15% percentage of Metakaolin as a replacement for cement when compared with control mix. The results of the test was carried out in 28 days.
- It was found that the use of a percentage of cement with Metakaolin leads to increasing the value of the crack load, and in addition to that, uses of Metakaolin as a replacement material of cement by weight gives an increase in failure load.

Figure 11 : Crack on the beam (0-350)

(Experimental)

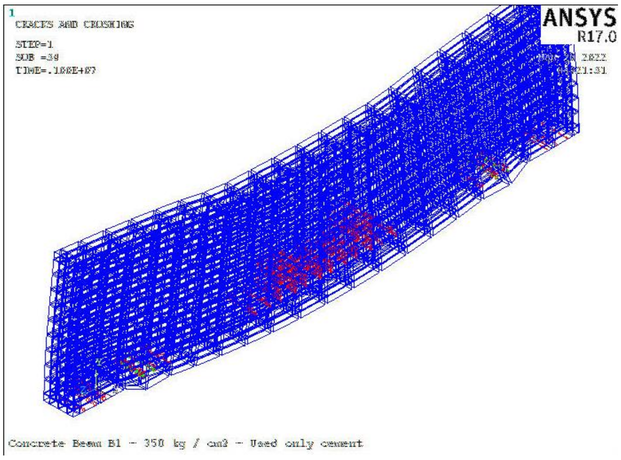

Figure 12 : Crack on the beam (0-350)

(Ansys)

Figure 13 : Crack on the beam (15-350)

(Experimental)

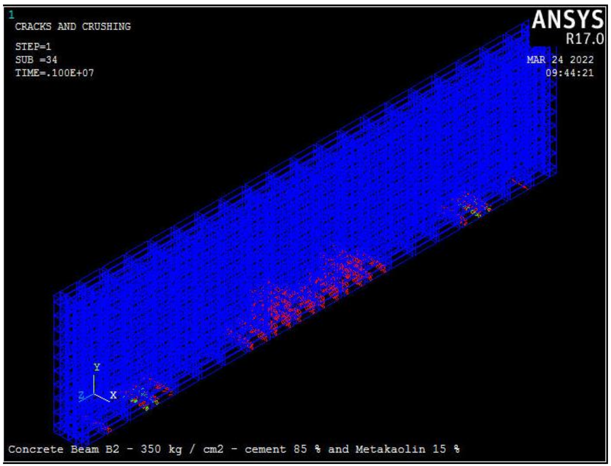

Figure 14 : Crack on the beam (15-350)

(Ansys)

6.6. Deflection analysis

- By using the data which is obtained from the finite element analysis (Ansys 17.0) for the beams, it is referred that increasing in values of load, increases the value of deflection as shown in figures (10 to 13).
- And note that when the cement content increases, the value of the deflection decreases as shown in **Table 12** .
- Also note that in the case of adding Metakaolin as a replacement material of cement it shows that its value of deflection decreases as shown in **Table10**.

7. Deflection of the beam

The differential equation for the deflection (y) of a member with length (L) under the bending moment M is:

$$\frac{d^2y}{dL^2} = -\frac{M}{EI} \qquad (1)$$

Where:

E = modulus of elasticity I= moment of inertia of member

The minus sign means that for a positive bending moment the curvature is negative. From the relation:

$$\frac{d^2M}{dL^2} = -P$$

We also have:

$$\frac{d^4y}{dL^4} = \frac{P}{EI}$$

The two equations above are the equations of the elastic line of a straight member, from which the deflections can be calculated. Maximum deflection for simply supported beam subjected to concentrated load at mid span is given as:

$$y_{max} = \frac{Pl^3}{48EI}$$

Table 12 : Max Load – Max Deflection

Model	Max Load (ton)	Max Deflection (cm)
Mix (0-250)	24.4	1.68
Mix (0-350)	25.2	1.42
Mix (15-250)	25.8	0.54
Mix (15-350)	27	0.57

8. Results of deflection form Ansys

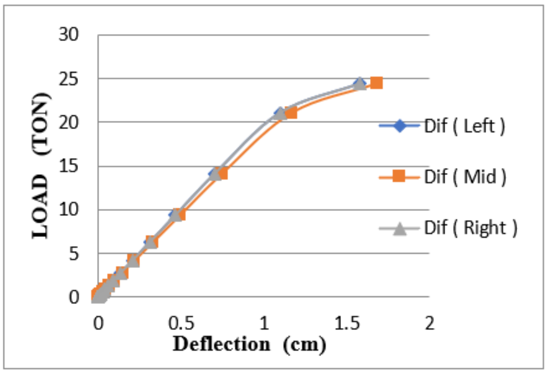

Fig 15: Deflection from Ansys (Mix 0-250)

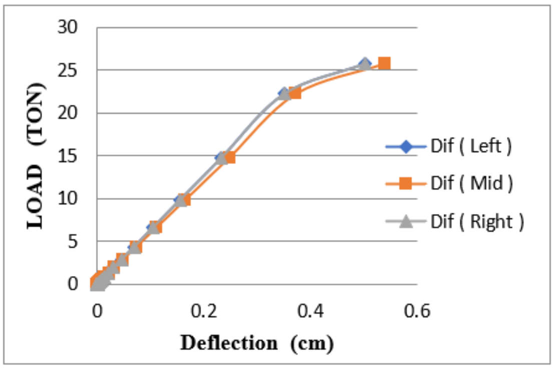

Fig 16: Deflection from Ansys (Mix 15-250)

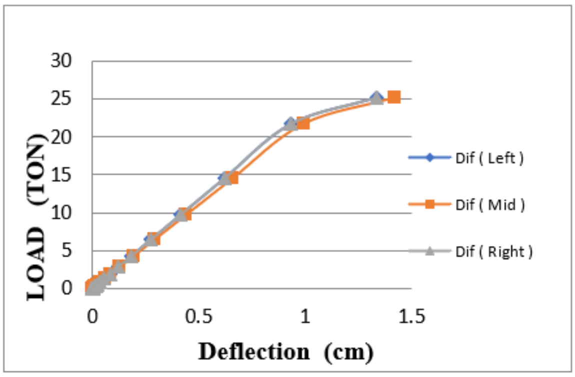

Fig 17: Deflection from Ansys (Mix 0 - 350)

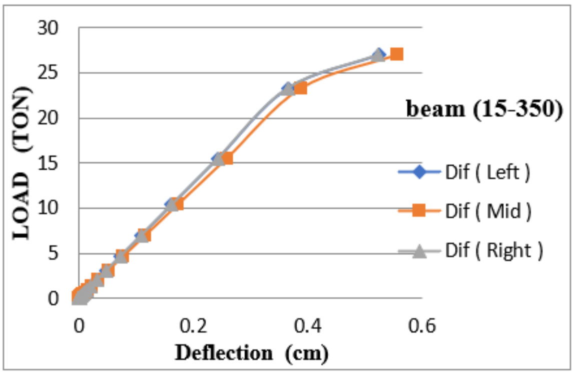

Fig 18: Deflection from Ansys (Mix 15 - 350)

- Shapes of analysis models on Ansys: -

a) Displacement on models shown on figures (19 to 22).

b) Strain on models shown on figures (23 to 26).

c) Stress on models shown on figures (27 to 30).

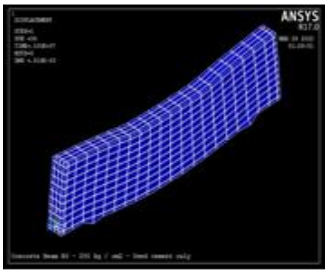

Fig 19: Displacement (0-250)

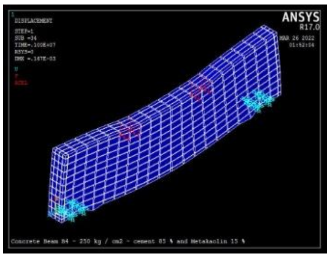

Fig 20: Displacement (15-250)

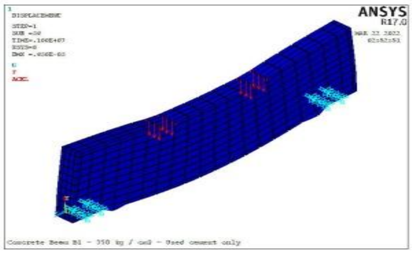

Fig 21: Displacement (0-350)

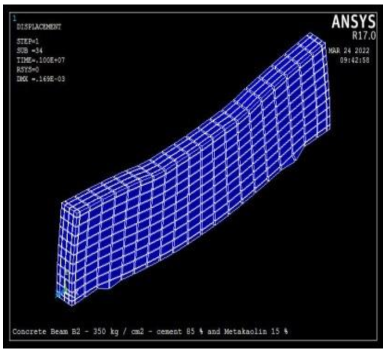

Fig 22: Displacement (15-350)

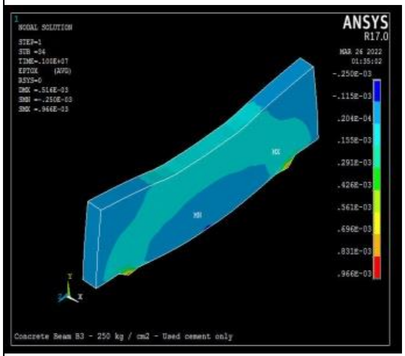

Fig 23: Strain (0-250)

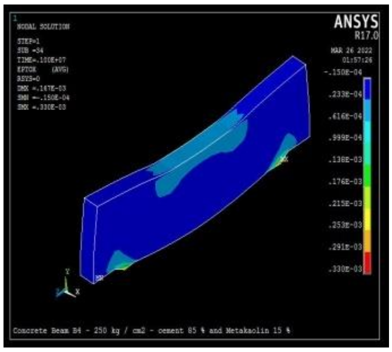

Fig 24: Strain (15-250)

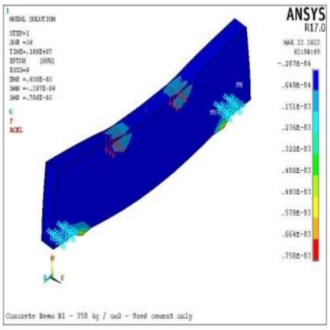

Fig 25: Strain (0-350)

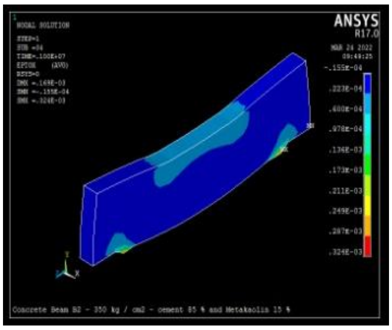

Fig 26: Strain (15-350)

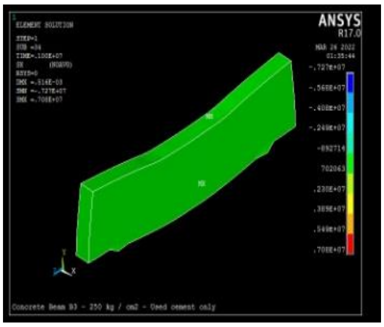

Fig 27: Stress (0-250)

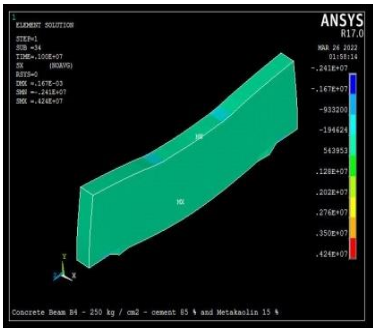

Fig 28: Stress (15-250)

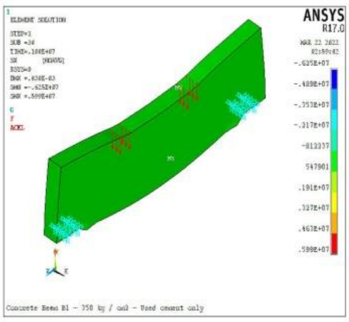

Fig 29: Stress (0-350)

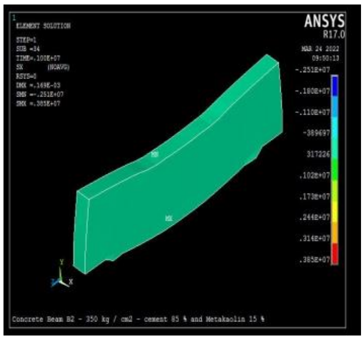

Fig 30: Stress (15-350)

Conclusions

- In this research, reinforced concrete beams were analyzed experimentally and by finite element method .
- The parameters used in this research are load value, deflection, and stress .

After analyzing the model, the following conclusions can be drawn:

1- The effect of metakaolin used as a substitute material with cement ratio leads to early resistance.
2- The use of Metakaolin as a substitution of a percentage of the weight of the cement gives an increase in the resistance by a rate ranging from 17.22% to 25.2 %.
3- The use of Metakaolin substitution in low resistors gives a better improvement rate than in high resistances.
4- As a percentage of metakaolin, the increase in concrete mix effectively increases compressive and flexural strength compared to conventional concrete by up to 15% metakaolin
5- The workability value decreases as a result of increasing the percentage of metakaolin in the concrete mix .
6- The value of strength of concrete increases with the increase in Metakaolin content up to 15% replacement of cement.
7- As the Percentage of Metakaolin powder in concrete increases, the workability value of concrete decreases.

References

[1] G. Murali, P. Sruthee, (2012).“ Experimental study of concrete with metakaolin as partial replacement of cement ”. International journal of emerging trends in engineering and development . Vol.4 .

[2] Vikasshrivastava , Rakeshkumar, (2012). “Effect of metakaolin and silica fume combination on concrete”. IJCSE vol 2.

[3] Efstratios G. Badogiannis, Ioannis P. Sfikas, Dimitra V. Voukia , Konstantinos G. Trezos, Sotirios G. Tsivilis (2015) . “ Durability of metakaolin Self-Compacting Concrete” . Construction and Building Materials . Volume 82 , Pages 133-141.

[4] R. San Nicolas , M. Cyr , G. Escadeillas , (2014) . “Performance-based approach to durability of concrete containing flash-calcined metakaolin as cement replacement” . Construction and Building Materials. Volume 55 , Pages 313-322.

[5] R.A.Ogale , Snehal S.Shinde , (2016) . “ Effect of Metakaolin and Fly Ash on The Strength of Concrete ” . International Journal of Advanced Research in Science Management and Technology . Volume 2 .

[6] R. San Nicolas , M. Cyr , G. Escadeillas , (2014) . “Performance-based approach to durability of concrete containing flash-calcinedmetakaolin as cement replacement” . Construction and Building Materials. Volume55 , Pages 313-322.

[7] Pacheco Torgal F, ArmanShasavandi, Said Jalali, (2011) . “Using metakaolin to improve the compressive strength and the durability of fly ash based concrete” . International seminar, innovation& valorization in civil engineering & construction materials . ISBN 987-9954-30-595-9.

[8] ErhanGu¨neyisi , Mehmet Gesog˘lu , KasımMermerdas¸ (2008) . “Improving strength, drying shrinkage, and pore structure of concrete using metakaolin” . Materials and Structures Volume 41, Pages 937–949.

[9] J. O. Akinyele, S. O. Odunfa, A. A. Famoye, (2017) . "STRUCTURAL BEHAVIOR OF METAKAOLIN INFUSED CONCRETE STRUCTURE". Nigerian Journal of Technology . Vol. 36, No. , pp. 331 –338.

[10] Sunny A. Jagtap , Mohan N. Shirsath , Sambhaji L.Karpe , (2017) . "Effect of Metakaolin on the Properties of Concrete " . International Research Journal of Engineering and Technology e-ISSN: 2395-0056 .. p-ISSN: 2395-0072.

[11] A.A. Ramezanianpour, H. BahramiJovein, (2012) . "Influence of metakaolin as supplementary cementing material on strength and durability of concretes" . Construction and Building Materials . Pages 470–479.Volume 30,

[12] Sunny A. Jagtap , Mohan N. Shirsath , Sambhaji L. Karpe , (2017) . "Effect of Metakaolin on the Properties of Concrete". International Research Journal of Engineering and Technology. Volume: 04 Issue: 07.

[13] AbidNadeem , Shazim Ali Memon , Tommy Yiu Lo, (2013). "Mechanical performance, durability, qualitative and quantitative analysis of microstructure of fly ash and Metakaolin mortar at elevated temperatures" . Construction and Building Materials. Volume 38 , Pages 338–347.

[14] F. Pacheco Torgal , ArmanShasavandi , Said Jalali , (2011) . " Using metakaolin to improve the compressive strength and the durability of fly ash based concrete" . International Seminar, innovation& valorization in civil engineering & construction materials. N°: 1P-251.

[15] M. Antoni, J. Rossen , F. Martirena , K. Scrivener, (2012). "Cement substitution by a combination of metakaolin and limestone" . Cement and Concrete Research . Volume 42, Issue 12 , Pages 1579–1589.

[16] A.A. Ramezanianpour, H. BahramiJovein, (2012). "Influence of metakaolin as supplementary cementing material on strength and durability of concretes". Construction and Building Materials . Volume 30 , Pages 470–479.