FLEXURAL BEHAVIOR OF REINFORCED CONCRETE BEAMS WITH NANO-METAKAOLIN

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Abstract-   Concrete is the most broadly utilized construction material in structural building because of its high structural strength and stability, using strength and high performance concrete has been expanding all through the world. Among the different techniques used to improve the strength and performance of concrete, utilization of Cement Replacement Material (CRM) like Meta-kaolin is a generally new approach. The understanding of fracture mechanism of reinforced concrete (RC) structure is vital and under this study its focusing to crack and deflection behavior for RC beam under static loading.
An experimental investigation has been carried out on 7-RC beam to investigate the behavior of reinforced concrete beams with 10% of Nano-Metakaolin in flexural to study effect of utilizing Nano-Metakaolin, effect of flexural reinforcement ratios, effect of compression reinforcement ratios and effect of characteristic strength of concrete.
 It is found that partial replacement of cement with Nano -Metakaolin has a greater influence on the tested beams by 122,107,107&125% for initial crack, ultimate load, maximum defection and toughness, with minimum flexural reinforcement ratio 1.29%, and minimum compression reinforcement ratio 0.44.
Keywords- Flexural Strength, Reinforced Concrete, Nano-Metakaolin (MK)

I.   INTRODUCTION

Concrete is one of most broadly utilized construction materials in the planet, with two billion tons set worldwide every year. It is appealing in numerous applications because it offers considerable strength at a relatively low cost. Concrete can generally be produced of locally available constituents, can be cast into a wide variety of structural configurations, and requires minimal maintenance during service. Enormous reviews have been done to investigate the likelihood of using an extensive variety of materials as partial replacement material for cement in the preparation of concrete. The utilization of supplementary cementations material in the preparation of concrete may result in major saving of energy, cost and reduction in environmental pollution. It is additionally enhances workability, strength, durability and chemical resistance of concrete. There are number of supplementary cementations material are accessible, for example, fly ash, metakaolin, silica fume, slag cement, rice husk, coconut shell etc.

The utilization of high strength concrete in structure application has been expanding around the world. A couple of years prior, a characteristic compressive strength of $40N/mm^2$ would have been viewed as high strength concrete, yet now it was turned out to be typical wonders. These days, concrete with a 28 days curing and has characteristic cube strength of $60N/mm^2$ or more will be considered as a high strength concrete. The accomplishment of such high strength concrete has been conceivable fundamentally through the introduction of materials such as Metakaolin. Metakaolin is the latest mineral to be commercially introduced to the concrete construction industry.

There are a few points of interest of fusing Metakaolin to produce high strength for high rise building. These include reductions in member thickness resulting in reduced foundation loads, increased rentable areas and smaller structural element, as well as high early strength development of concrete which allows early stripping of formwork, therefore accelerating concrete construction. The raw material contribution to the manufacture of Metakaolin (MK) is kaolin clay. Kaolin is a fine, white, clay mineral that has been generally utilized in the manufacture of porcelain. It is

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believed that the term kaolin is derived from the Chinese Kaoling, which translates loosely to white hill and has been related to the name of a mountain in China that yielded the first kaolins that were sent to Europe. Kaolinite is the mineralogical term that is applicable to kaolin clays. Kaolinite is defined as a typical mineral, hydrated aluminum disilicate, $Al_2Si_2O_5(OH)$.

Metakaolin (MK) is a supplementary cementing material that complies with ASTM C 618, Class N[1] pozzolan specifications and it is considered as a pozzolanic material which is without direct cementitious value, yet will, within the presence of moisture, reacts chemically with calcium hydroxide (CH) to form compounds possessing cementitious properties. It is acquired by the calcinations of kaolin at a temperature extending in the vicinity of 500°C and 800°C. The material is a fine, white, clay mineral MK has been known to enhance strength and porerefinement at relatively early ages [2].

II.   PREVIOUS RESEARCH

P. Dinakar et.al. [3], by utilizing Metakaolin and cement with low water/binder ratio of 0.3, high performance concretes can be produced. From results it can be realized that Cube Compressive strength, Splitting tensile strengths and elastic modulus results shown higher values at 10% replacement of cement by Metakaolin.

Nova John [4], the outcomes appears by the partial replacement of cement with Metakaolin helps in achieving high strengths in concrete. At 15% replacement of cement with Metakaolin content improves the strength characteristics such as of Cube Compressive Strength, Split Tensile Strength and Flexural Strength.

K.Srinivasu et.al.[5], Better Outcomes are accomplished by adding mineral admixtures like Metakaolin with silica fume, flyash and steel fibers in HPC. Water absorption is improved by use of Metakaolin in concrete which increases density.

M. Nazeer, R. Arun Kumar [6], the impact resistance of both binary blended and ternary blended mixes shows remarkable improvement compared to concrete mix with cement as the only binder.

III.   EXPERIMENTAL PROGRAM

Materials and Methods
A) Materials
 1. Cement
The cement utilized during the investigation is 52- grade Ordinary Portland Cement. The cement was purchased from single source. The specific gravity of the above cement was 3.15 and it is conforming to Egyptian Standard Specification [7].

2. Aggregates
Natural river sand was used as fine aggregate and broken granite stones of size 20mm was used as coarse aggregate. Fine aggregates confirm to Zone II grading with specific gravity 2.64 and bulk density of 1560kg/m^3 respectively. The specific gravity of coarse aggregate was 2.83.

3. Water
Potable water available in laboratory was used in this investigation for making concrete.

4. Nano - Metakaolin
Metakaolin is a dehydroxylated form of the clay mineral kaolinite. Metakaolin was ground in a heat-treated at 800° C for 2 hr high speed ball grinding mill and it was reduced to nano scale, and investigated using SEM Quanta FEG 250 at Suez and Sinai Metallurgical and Materials Research Center of Scientific Excellence (SSMMR-CSE), Suez University, Suez, Egypt , Fig. 1 a and b respectively.

It was observed that the particles sizes were decreased after heat-treatment and also the layered were reached to a nano-scale. It was reported that the nano-layer thickness and the Sub micron layer is more useful for concrete properties

Fig. 1 a: Row Material Metakaolin   Fig. 1 b: Nano - Metakaolin

Object and Scope:
The experimental program included testing of 7-RC beams to investigate the behavior of reinforced concrete beams with Nano-Metakaolin in flexural to study
I.   Effect of using Nano-Metakaolin.

II.   Effect of flexural reinforcement ratios.

III.   Effect of compression reinforcement ratios.

IV.   Effect of characteristic strength of concrete.

Description of the tested beams:
This study involved testing of seven concrete beams; two-span concrete beams with rectangular cross-sections of 100*200 mm, total length of 2050 mm and tested length of 1750 mm were tested. Table (1) shows the details of tested beams, All beams were divided into four groups of different reinforced concrete beams; group one contains control beam with reinforcement (As=2Φ12mm) and (AS$^\backslash$ =2Φ8mm) and ø6mm @20cm as shear reinforcement. Group two contains three beams with characteristic strength 25Mpa and 10% Nano-Metakaolin and different ratios of flexural reinforcement as shown in table (1). Group three contains two beams with characteristic strength 25Mpa and 10% Nano-Metakaolin and different ratios of compression reinforcement as shown in table (1). Group four contains a beam with characteristic strength 35Mpa and 10% Nano-Metakaolin and reinforcement (As=2Φ12mm) and (AS$^\backslash$ =2Φ8mm) and ø6mm @20cm shear reinforcement as shown in figs. (2-5).

Table (1) Details of tested beams.

Group No	Beam No	Dim. (mm)		f_{cu} Mpa	Reinforcement				Nano-Meta kaolin (%)
		width	depth		Flex. Rfmt	Flex. Rfmt Ratio (%)	Comp. Rfmt	$\alpha=A_s^\backslash/A_s$	
G1	CB1				2Φ12	1.29	2Φ8	0.44	-
G2	B2				2Φ10	0.89	2Φ8	0.64	10
	B3				2Φ12	1.29	2Φ8	0.44	10
	B4	100	200	25	3Φ12	1.93	2Φ8	0.296	10
G3	B5				2Φ12	1.29	2Φ6	0.25	10
	B6				2Φ12	1.29	2Φ10	0.69	10
G4	B7			35	2Φ12	1.29	2Φ8	0.44	10

Flex. Rfmt: Flexural Reinforcement   Comp. Rfmt: Compression Reinforcement

Fig.2 Details of reinforcement and dimensions in mm for group 1

Fig.3 Details of reinforcement and dimensions in mm for group 2

Fig.4 Details of reinforcement and dimensions in mm for group 3

Fig.5 Details of reinforcement and dimensions in mm for group 4

Loading Arrangement:
The load was applied by universal testing machine of 2000 KN. Full capacity through a loading plate and a spreader beam to give two-point loading (60 cm) as shown in Fig. 6

Fig.6 Loading Arrangement of tested beams

V.   RESULTS AND DISCUSSION

Table 2 demonstrates the actual f_{cu}, cracking load, ultimate load, maximum deflection of tested specimens and type of failure.

Table 2. The results of tested beams

Group No.	Beam No.	Actual f_{cu} (Mpa)	Cracking Load (kN)	Ultimate Load (kN)	Max. Deflection (mm)	Toughness (kN.mm)	Type of failure
G1	CB1	27	18	53	28	1081	flexural-shear
G2	B2	31	14	37.7	28.8	876	flexural-shear
	B3	30.5	22	56.7	30	1353	flexural-shear
	B4	30	23	70.6	32.5	1588	shear
G3	B5	30.5	10	28.4	23.2	163	shear
	B6	31	22	57.2	48.5	2425	flexural-shear
G4	B7	39	25	62	32	1524	shear

1. Mode of failure
All tested beams exhibited a conventional failure in which the beam failed through yielding of the steel reinforcement followed by crushing in concrete by large strains. Fig. 7 shows the crack patterns of tested beams.

From table 2, it can be seen that, initial cracking load of B3 with 10% of Nano-Metakaolin to CB1 is 122%. Initial cracking load of B2, B4 with different flexural reinforcement ratios 0.89, 1.93% to B3 with flexural reinforcement ratios 1.29% are 64 and 105% respectively.

Initial cracking load of B5, B6 with different compression reinforcement ratios 0.25, 0.69 to B3 with compression reinforcement ratios 0.44 are 45% and 100% respectively.

Initial cracking load of B7; with 35 Mpa characteristic strength to B3; with 25 Mpa characteristic strength is 114%.
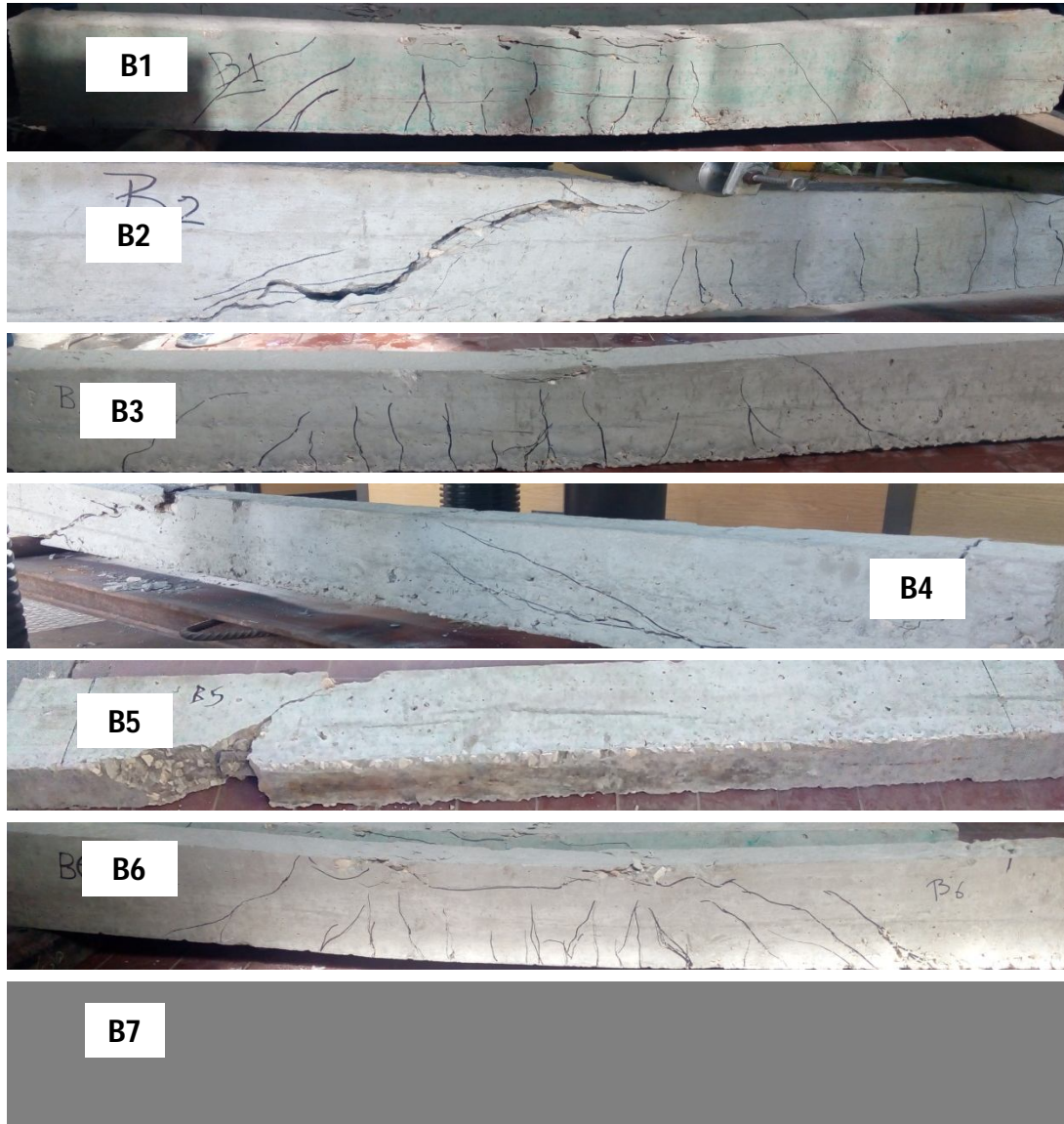

Fig.7 Crack Patterns of Tested Beams

2. Load–deflection relationship

Load versus mid-span deflection relationships are shown in Figs. 8-11, while table 2 summarizes the structural test results. The ultimate load was defined as the maximum recorded load during testing of each beams.

From table 2, it can be seen that, ultimate load and maximum deflection of B3 with 10% of Nano-Metakaolin to CB1 are 107% and 107% respectively. Ultimate load and maximum deflection of B2, B4 with different flexural reinforcement ratios 0.89, 1.93% to B3 with flexural reinforcement ratios 1.29% are (66%, 125%) and (96%, 108%) respectively. Ultimate load and maximum deflection of B5, B6 with different compression reinforcement ratios 0.25, 0.69 to B3 with compression reinforcement ratios 0.44 are (50%, 101%) and (77%, 162%) respectively. Ultimate load and maximum deflection of B7; with 35 Mpa characteristic strength to B3; with 25Mpa characteristic strength is 109% and 107% respectively.

Fig.8 Load-Deflection curve of B1 & B3

Fig.9 Load-Deflection curve of B2, B3 & B4

Fig.10 Load-Deflection curve of B3, B5 & B6

Fig.11 Load-Deflection curve of B3& B7

VI.   EVALUATION OF TEST RESULTS

1. Effect of using Nano-Metakaolin
Fig. 12 shows the relationship of initial crack, ultimate load, maximum defection and toughness of tested beams CB1 (control beam) and B3 with 10% of Nano -Metakaolin, where using Nano -Metakaolin with 10% increase initial crack, ultimate load, maximum defection and toughness of tested beams by 122,107,107 and 125% respectively.
Using Nano-Metakaolin with 10% enhancing the properties of used concrete by 122,107,107&125% for initial crack, ultimate load, maximum defection and toughness of tested beams

Fig.12 Initial crack, ultimate load, maximum defection and toughness
of tested beams CB1& B3

2. Effect of flexural reinforcement ratios.
Fig. 13 shows the relationship of flexural reinforcement ration of B2, B3 and B4 with different flexural reinforcement ratios 0.89, 1.29 & 1.93% and their percentage values of initial crack, ultimate load, maximum defection and toughness of tested beams to values of B3.
Increasing flexural reinforcement ration from 0.89% to 1.29% increase initial crack, ultimate load, maximum defection and toughness of tested beams by 157,150,105 and 154% respectively, whereas increasing flexural reinforcement ration from 1.29% to 1.93% increase initial crack, ultimate load, maximum defection and toughness of tested beams by 105,125,108 and 117% respectively.

Increasing flexural reinforcement ration up to 1.29% has a significant effect on initial crack, ultimate load, maximum defection and toughness of tested beams so it is recommended that minimum flexural reinforcement ratio 1.29%.

Fig.13 Flexural reinforcement ratios and their percentage values with B3 (ρ=1.29%)

3. Effect of compression reinforcement ratios.

Fig.14 shows the relationship of compression reinforcement ration of B5, B3 and B6 with different flexural compression ratios 0.25, 0.44 & 0.69 and their percentage values of initial crack, ultimate load, maximum defection and toughness of tested beams to values of B3.

Increasing compression reinforcement ration from 0.25 to 0.44 increase initial crack, ultimate load, maximum defection and toughness of tested beams by 220%,199%,129% and 830% respectively, whereas increasing flexural reinforcement ration from 0.44 to 0.69 increase initial crack, ultimate load, maximum defection and toughness of tested beams by 100%,101%,162% and 179% respectively.

Increasing compression reinforcement ration up to 0.44 has a significant effect on initial crack, ultimate load, maximum defection and toughness of tested beams so it is recommended that minimum compression reinforcement ratio 0.44

Fig.14 Compression reinforcement ratios and their percentage values with B3 (α=0.44)

4. Effect of characteristic strength of concrete.

Fig. 15 shows the relationship of initial crack, ultimate load, maximum defection and toughness of tested beams B7; with 35 Mpa characteristic strength to B3; with 25 Mpa characteristic strength, where using 35Mpa characteristic strength of concrete with Nano-Metakaolin with 10% increase initial crack, ultimate load, maximum defection and toughness of tested beams by 114,109,107 and 127% respectively.

Using concrete with 35Mpa characteristic strength of and Nano-Metakaolin with 10% has a significant effect on the initial crack and toughness of tested beams.
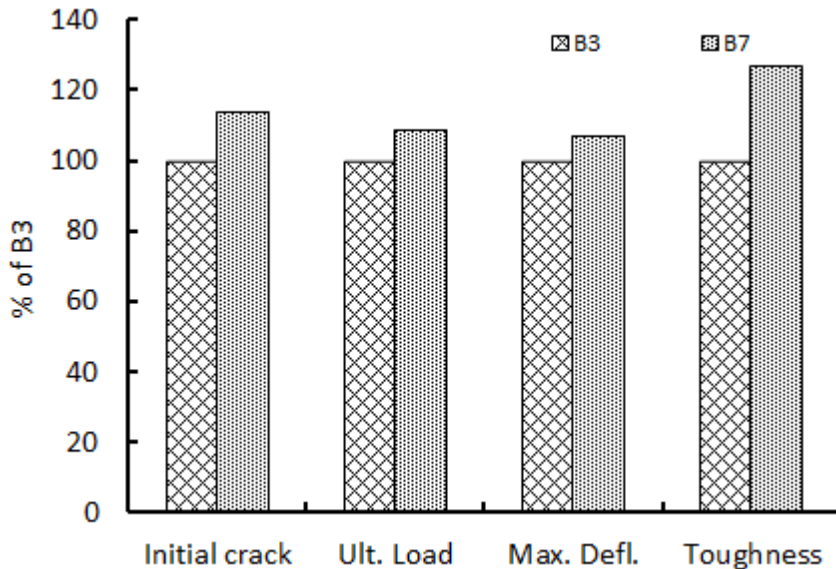

Fig.15 Initial crack, ultimate load, maximum defection and toughness
of tested beams B7& B3

VII.   CONCLUSION

Based on the experimental investigations the following conclusions are drawn:

I.   Using Nano-Metakaolin with 10% has a greater influence on the tested beams by 122,107,107&125% for initial crack, ultimate load, maximum defection and toughness.

II.   Increasing flexural reinforcement ration up to 1.29% has a significant effect on the properties of reinforced concrete beams and it is recommended that minimum flexural reinforcement ratio 1.29%.

III.   Increasing compression reinforcement ration up to 0.44 has a significant effect on the properties of reinforced concrete beams and it is recommended that minimum compression reinforcement ratio 0.44.

IV.   Using concrete with 35Mpa characteristic strength of and 10% of Nano-Metakaolin has a significant effect on the initial crack and toughness of tested beams.

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