Al-Azhar University Civil Engineering Research Magazine (CERM)
Vol. (45) No. (1) January 2023

Nano effect on the Behavior of Reinforced Concrete

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الملخص العربى :

تعتبر صناعة الأسمنت بصفة خاصة أحد المصادر الهامة لانبعاثات غاز ثانى أكسيد الكربون إلى الهواء الجوي. ونظرا لما يحدثه هذا النشاط من آثار ضارة في التغيرات المناخية الناشئة حاليا والتلوث البيئي بالمخلفات والنواتج الثانوية، فإن الأمر يستوجب ضرورة العمل على خفض كمية وحدة هذه المؤثرات البيئية. لذا فقد أصبحت الحاجة ماسة وملحة إلى العمل على تثبيت تركيزات ثانى أكسيد الكربون فى الغلاف الجوي وذلك من خلال تطبيقات التكنولوجيات الحديثة وإجراء تغييرات كبيرة فى مكونات مواد البناء بحيث تساعد على خفض كمية الانبعاثات الغازية بشكل يسمح بالمضي قدما في التنمية الاقتصادية فى مصر على نحو مستدام، وهو الهدف الأسمى لهذه الدراسة. ويمكن للعديد من تخصصات الهندسة المدنية الاستفادة من النانو تكنولوجي سواء في مجال التصميم أو التنفيذ وذلك من خلال صناعة مواد إنشائية جديدة ذات خواص فريدة وإنتاج مركبات أخف وأكثر قوة ومقاومة للحريق وعمل بوليمرات مشبعة بجزيئات النانو الطينية وغيرها. ونظرا لما قامت به الحكومة المصرية من إدراج إنتاج مادة الميتاكاولين كأحد الصناعات الإستراتيجية بالاستراتيجية القومية للعلوم والتكنولوجيا للتنمية المستدامة 2030، فإن الهدف المبدئي من هذه الدراسة هو بيان مدى صلاحية استخدام الميتا كاولين كإضافة أسمنتية بوزولانية وكذا دراسة تأثيرها على خصائص الأسمنت البورتلاندى والخرسانة. حيث تستخدم هذه المواد كإضافات للخرسانة بهدف خفض نسبة الأسمنت المستخدم وبالتالي خفض التلوث الجوي وتوفير الطاقة وخفض التكلفة. هذا بالإضافة إلى الارتقاء بخصائص الخرسانة ودعم قدرتها على الاستدامة فى مواجهة الظروف البيئية المحيطة. إن الاحتياج إلى استخدام المواد المحلية مثل الميتاكاولين كمواد بوزولانية فى أعمال الخرسانة فى مصر، قد جعل دراسة إمكانية استخدام المتاح منها حاليا وبحث تأثيره على خصائص الأسمنت والخرسانة أمرا فائق الأهمية.

Abstract

There are many reasons needed for continuous evolution in concrete technology; one of them concern on the greenhouse gas emission and depletion of natural resource as a result of high production of Portland cement. Many solutions are used to solve these problems; one of them is using cement replacement materials in concrete like metakaolin (in micro or Nano scale) which offered positive effect on the properties of cement concrete. The use of supplementary cementitious materials (SCMs) is fundamental in developing low-cost construction materials for use in developing countries. The construction industry has recently focused on the use of sustainable and innovative building materials, which called for the production of many supplementary cementitious materials with concrete to make the concrete produced durable and sustainable. As an available and high-quality supplementary cementing materials (SCMs), Consumption of Metakaolin (MK) is proposed to replace Portland cement to improve concrete quality and reduce the negative effects of cement industry on the environment. With that being said, it is necessary to summarize the recent finding and gaps on the effect of replacing Portland-cement by MK and Nano Metakaolin (NMK) in different replacement levels on various fresh and hardened properties of concrete. The main purposes of the usage of SCMs are to decrease the material cost and the environmental impact caused during material production by a partial replacement of cement. In this research, the HSC will produce using cheap available materials such as hybrid fiber (proportion between steel fibers and polypropylene fibers) with Nano material. The results encourage the use of kaolin powder as pozzolanic material for partial cement replacement in producing HSC and to compensate for environmental, technical and economic issues caused by cement production. The tests implemented in this study confirmed that metakaolin constitutes a promising material as a substitute for the cost prohibitive silica fume and has the potential to produce high strength concrete. The results also showed that fiber-reinforced concrete mixtures using nano-meta kaolin as a partial replacement of cement can be successfully used as a construction material in pouring reinforced concrete beams.

Keywords: Cement replacement, HSC, Hybrid Fiber, Metakaolin, Nano Metakaolin

1. Introduction

Environmental concerns, stemming from high-energy expense and CO2 emission associated with cement manufacture, have brought pressures to reduce consumption through the use of supplementary materials. International statistical studies have proven that the cement industry ranks second in the ranking of the most dangerous sources of carbon dioxide emissions in the world, because it alone produces about (7%) of the total industrial emissions of carbon dioxide. Given the harmful effects of this activity on the currently emerging climate changes and environmental pollution with waste and by-products, it is necessary to work to reduce the quantity and unit of these environmental influences. Therefore, it has become an urgent to work on making major changes in the components of building materials so as to help reduce the amount of gaseous emissions in a way that allows moving forward in economic development in Egypt on towards sustainable, which is the overarching goal of this study. With the development of modern civil engineering projects toward high long-span bridges and large-scale water conservancy projects, the demand for concrete having strength, rigidity, durability, and crack resistance continues to increase. However, traditional concrete cannot meet these requirements. This issue led to the development of a new concrete technology, high-strength concrete (HSC), which can bear a load capacity of up to approximately 90 MPa.
By addition of some pozzolanic materials, the various properties of concrete like workability, durability, strength, resistance to cracks and permeability can be improved. This research elaborates the findings of different works on partial replacement of cement replacement for

sustainable and eco-friendly concrete for the construction industry. The aim of this work is to study the effect of MK and NMK on the mechanical properties of fresh and hardened concrete to reach to high strength concrete as possible with the optimum workability. The ordinary concrete has low tensile strength and brittle in nature. The tensile strength can be increased by the use of fibers in concrete. From the available literature reviewed, there are still divergent views on the optimum dose of metakaolin as a pleasant replacement material for cement in the production of high strength concrete (HSC).

Fiber reinforced concrete (FRC) was developed to get rid of the faults related to cement based materials such as low tensile strength, poor fracture toughness and brittleness of cementitious composites. In fact, no single fiber-reinforced concrete has the perfect mechanical properties. So, this research has an orientation to discuss the mechanical properties of the hybrid fiber reinforced concrete, such as a proper proportion between steel fibers and polypropylene fibers to concrete. Two types of fiber are blended so the material can accomplish the advantageous performance of each fiber. Since the hybrid fibers have certain complementarity and synergy, the high–modulus steel fibers can effectively enhance the mechanical properties of RC, while the low-modulus polypropylene fibers have certain advantages in improving the toughness of RC. The production of economical and eco-friendly HSC on a large scale was the goal of this experimental work.

2. Previous research

D. T. Rahane, et al. [1] focused on the effect of steel fiber content on the mechanical properties and concrete ductility of Steel Fiber Concrete with Metakaolin. Test results showed that addition of steel fibers to concrete changes its brittle mode of failure into a more ductile one and improves the concrete ductility. They concluded that addition of Metakaolin has enhanced the properties of hardened concrete and surface resistance increases when compared to plain concrete. **Ghugal et. al.** [2] showed that, as the content which is Fiber and metakaolin in concrete increases, the wet density is following the upside trend. **G. Jayakumar, et al.** [3] showed that Compressive and tensile strength of mix with HF (combination of SF and PPF) are found to be higher than other mixes. **Hamdy, et al.** [4] carried out an experimental investigation on the mechanical behavior of high strength concrete made with high percentages of Metakaolin and hybrid fibers with volume fractions of 0.25% and 0.5%. The combined effect of hybrid fiber and Metakaolin showed that the optimum dose of MK is 15% at all testing ages. They revealed that, there was a significant gain in split tensile strength due to Metakaolin and hybrid fiber. **Patel and Kulkarni** [5] observed that the compressive strength of concrete increased with addition of Polypropylene fibers when compared to the control specimen. **P. Dinkar, et al.** [6] studied the effect on mechanical and durability properties of high strength concrete by incorporating metakaolin at a constant water/binder ratio of 0.3. They observed that 10% replacement level was the optimum level regarding compressive, splitting tensile strength, and the elastic modulus. Beyond 10% replacement levels, the strength was decreased but remained higher than the control mixture. They also showed that in durability properties, MK concretes have exhibited high resistance compared to control and the resistance increases as the MK percentage increases. They also showed 0.42% and 9% enhancement in the 28 days splitting tensile strength with the inclusion of 5% and 10% MK, respectively. **R. V. Balendran et al.** [7] showed that the low volume of fiber improves remarkably toughness, flexural and splitting tensile strength. **Seok-Joon & Hyun-Do** [8] test result showed that steel fiber volume fraction does not have a significant effect on the modulus of elasticity of SFRC. They also showed that the flexural strength, toughness and the equivalent flexural strength ratio significantly increase in fiber content. By addition of MK and steel fibers, **Shelorkar Ajay, et. al.** [9] showed that there was an increase of tensile strength by 26.94% when compared with control concrete mix. **Shen et al.**, [10] studied the effect of metakaolin on hydration, microstructure, and volume stability of steam cured high strength concrete. They concluded that hydration of cement is accelerated by the presence of metakaolin. Study on concrete properties of high strength fiber reinforced concrete with metakaolin was done by **Shikhare V. B. et. al.** [11]**.** They showed that the mechanical strength was increased due to partial replacement of Metakaolin and steel fibers. **Vinod B. Shikhare, et. al.** [12] showed that the split tensile strength and the ductility are increased by addition of MK and steel fibers. **Yusof et. al.** [13] showed that concrete with short SF performs better in compression as compared to concrete with longer SF.

3. Objectives

This study, is an attempt made to understand the influence of metakaolin (MK) and nano metakaolin (NMK) as a partial replacement substance for cement in high strength concrete of grade M60. <u>The main objectives of this study can be summarized as follows</u>**:** (1) Studying the viability of using meta-kaolin (manufactured from natural kaolin taken from the quarries of the Abu Zenima area - South Sinai) as a pozzolanic material to replace increasing proportions of Portland cement. (2) Studying the use of different substitution ratios of metakaolin (10%, 15%, 20%, 30%, 40%, 50%) of cement weight. (3) Studying the influence of (0.20% and 0.40%) content of steel fiber, polypropylene fiber and hybrid mixture fiber on some mechanical properties of concrete**.** (4) Studying the effect of using metakaolin (MK) and ultrafine metakaolin (nano-meta-kaolin, NMK) on the mechanical properties of reinforced concrete with different types of fibers. (5) Estimation of the best ratio (or proportions) to replace cement in a mixture of Nano Meta Kaolin (NMK) and Portland Cement (OPC)**.** (6) To initiate a new application area, as fibrous concrete with MK and NMK should be designed to perform with adequate strength, sufficient ductility, high durability, and adequate workability.

4. Experimental Program

4.1 General

The investigation was developed in two stages included the following experiments and tests: (1) Conducting Complete chemical analyzes of kaolin, meta-kaolin and Portland cement using X-ray fluorescence (XRF). (2) Mineralogical characterization of the raw materials used, their mixtures, and the changes that occurred to them, using X-Ray Diffraction (XRD). (3) Examination using [Infra-Red (IR) Spectra] to study the behavior of metakaolin produced with cement as a pozzolanicity testing material and to estimate the best ratio (or proportions) of the (MK/OPC) mixture. A total of 420 test specimens (cubes and cylinders) were arranged in five groups, each group consisted of 84 specimens as follows:

Group 1: Consisted of 12 test specimens as control cubes and cylinders with 0 % of SCMs and 0 % volume fraction of fiber, in addition to 72 test cubes and cylinders specimens with 0 % of MK replacement of cement weight and different volume fraction (0.20 % and 0.40 %) of steel fiber (SF), polypropylene fiber (PPF) and hybrid mixture (HM).

Group 2: Consisted of 12 test specimens as reference cubes and cylinders with 10 % of MK content and 0 % volume fraction of fiber, in addition to 72 test cubes and cylinders specimens with 10 % of MK replacement of cement weight and different volume fraction (0.20 % and 0.40 %) of SF, PPF and HM.

Group 3: Consisted of 12 test specimens as reference cubes and cylinders with 15 % of MK content and 0 % volume fraction of fiber, in addition to 72 test cubes and cylinders specimens with 15 % of MK replacement of cement weight and different volume fraction (0.20 % and 0.40 %) of SF, PPF and HM.

Group 4: Consisted of 12 test specimens as reference cubes and cylinders with 20 % of MK content and 0 % volume fraction of fiber, in addition to 72 test cubes and cylinders specimens with 20 % of MK replacement of cement weight and different volume fraction (0.20 % and 0.40 %) of SF, PPF and HM.

Group 5: Consisted of 12 test specimens as reference cubes and cylinders with 15 % of NMK content and 0 % volume fraction of fiber, in addition to 72 test cubes and cylinders specimens with 15 % of NMK replacement of cement weight and different volume fraction (0.20 % and 0.40 %) of SF, PPF and HM.

Summary of the concrete cubes & cylinders test specimens for different tests is shown in Table (1).

Table (1): Summary of the Concrete Cubes & Cylinders Test Specimens

Group No.	No. of compression test specimens (Cubes)			No. of split tensile test specimens (Cylinders)
	3 days age	7 days age	28 days age	28 days age
G1	21	21	21	21
G2	21	21	21	21
G3	21	21	21	21
G4	21	21	21	21
G5	21	21	21	21
Total	105	105	105	105

4.2 Characteristics of the Used Materials

The materials used in this study for concrete production are ordinary Portland cement, admixtures, tap drinking water, natural sand, natural crushed stone (dolomite), MK, NMK, SF, PPF and HMF. These materials were chosen carefully. Tests to determine the properties of these materials were carried out according to the Egyptian Standard Specifications (ESS) or the ASTM standards.

4.2.1 Meta-Kaolin (MK)

Table (2) gives the chemical analysis of raw kaolin (abu-Zinema quarries – Southern Sinai) and metakaolin produced after heat treatment at (ASCE).

Table (2): Chemical Analysis of Raw Kaolin and Metakaolin Produced After Heat Treatment at (ASCE).

Sample name	SiO_2	Al_2O_3	TiO_2	Fe_2O_3	CaO	SO_3	Na_2O	K_2O	MgO	P_2O_5	Cl^-	LOI	Total
Kaolin	54.40	30.56	1.64	0.88	0.21	0.24	0.30	0.07	0.09	0.14	0.11	11.40	99.80
Metakaolin	62.37	31.60	2.60	1.47	0.26	0.15	0.13	0.12	0.16	0.10	0.03	1.16	99.99

Figure (1) shows the mineralogical characterization pattern, using X-ray fluorescence (XRF), for metakaolin produced after heat treatment at (ASCE).

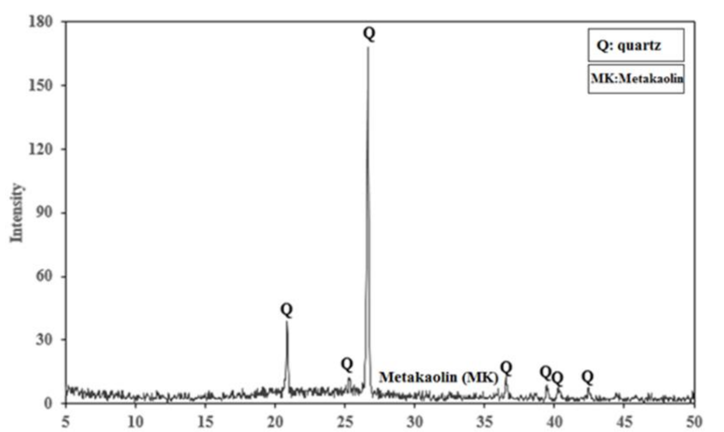

Figure (1): XRF Pattern for Metakaolin Produced at (ASCE).

4.2.2 Nano Metakaolin (NMK)

Metakaolin (MK) was ground in a high-speed ball grinding mill and was reduced to nano scale to produce nano metakaolin (NMK). The particle size of the NMK produced in the ball grinding mill was up to 100 nm. In the present study NMK added by 15% of cement weight, group 5.

Table (3) gives the chemical composition of the used nano metakaolin (NMK).

Table (3): Chemical Composition of Nano Metakaolin (NMK)

Chemical composition	Nano metakaolin (%)
Silica (SiO_2)	65.0
Alumina (Al_2O_3)	32.12
Ferric oxide (Fe_2O_3)	0.25
Calcium oxide (CaO)	0.01
Magnesium oxide (MgO)	0.01
Sodium oxide (Na_2O)	0.03
Potassium oxide (K_2O)	0.05
Titanium dioxide (TiO_2)	2.40
Loss on ignition (LOI)	0.11

4.2.3 Steel Fibers (SFs)

The properties of the used SF, according to the manufacture information, are given in table 4.

Table (4): Typical Properties of the Used Steel Fibers

Property	Description*
Steel fiber type	Hocked end steel fiber
Fiber diameter (D), mm	1.0
Fiber length (L), mm	30.0
Aspect ratio (L/D)	30.0
Tensile strength (N/mm^2)	900

*Steel fiber properties were provided by the manufacturer.

4.2.4 Polypropylene Fiber (PPF)

The properties of the used PPF, according to the manufacture information are given in table 5.

Table (5): Typical Properties of the Used Polypropylene Fiber (PPF)

property	Description*
Fiber type	Monofilament polypropylene fiber
Fiber length (L), mm	12.0
Fiber nominal diameter (D), micron	18.0
Nominal Density (gm/cm^3)	0.91
Specific surface area (m^2/kg)	250.0
Acid resistance	High
Alkali resistance	100%

*Fiber properties were provided by the manufacturer.

4.3 Geometry & Details of the Concrete Cubes & Cylinders Test Specimens

A large number of cube specimens of dimensions 150 x 150 x 150 mm and cylinder specimens of dimensions 150 x 300 mm were cast. Table (6) shows the details of the concrete cubes & cylinders test specimens.

4.4 Concrete Mix Constituents

A Concrete mix design was made to determine the concrete mix constituents that achieve the target specified compressive strength (60 N/mm^2) of the hardened concrete at 28 days test age. Table 7 shows the concrete mix proportion required for 1 cubic meter of fresh concrete.

Table (6): Details of the Concrete Cubes & Cylinders Test Specimens

Group no.	Concrete mix	% Of SCMs replacement of		% Of fiber content by volume fraction		
		MK	NMK	SF	PPF	HMF
G1	MK0F0	0%	0%	0%	0%	0%
	MK0SF0.20			0.20%	0%	0%
	MK0PPF0.20			0%	0.20%	0%
	MK0HM0.20			0%	0%	0.20%
	MK0SF0.40			0.40%	0%	0%
	MK0PPF0.40			0%	0.40%	0%
	MK0HM0.40			0%	0%	0.40%
G2	MK10F0	10%	0%	0%	0%	0%
	MK10SF0.20			0.20%	0%	0%
	MK10PPF0.20			0%	0.20%	0%
	MK10HM0.20			0%	0%	0.20%
	MK10SF0.40			0.40%	0%	0%
	MK10PPF0.40			0%	0.40%	0%
	MK10HM0.40			0%	0%	0.40%
G3	MK15F0	15%	0%	0%	0%	0%
	MK15SF0.20			0.20%	0%	0%
	MK15PPF0.20			0%	0.20%	0%
	MK15HM0.20			0%	0%	0.20%
	MK15SF0.40			0.40%	0%	0%
	MK15PPF0.40			0%	0.40%	0%
	MK15HM0.40			0%	0%	0.40%
G4	MK20F0	20%	0%	0%	0%	0%
	MK20SF0.20			0.20%	0%	0%
	MK20PPF0.20			0%	0.20%	0%
	MK20HM0.20			0%	0%	0.20%
	MK20SF0.40			0.40%	0%	0%
	MK20PPF0.40			0%	0.40%	0%
	MK20HM0.40			0%	0%	0.40%
G5	NMK15F0	0%	15%	0%	0%	0%
	NMK15SF0.20			0.20%	0%	0%
	NMK15PPF0.20			0%	0.20%	0%
	NMK15HM0.20			0%	0%	0.20%
	NMK15SF0.40			0.40%	0%	0%
	NMK15PPF0.40			0%	0.40%	0%
	NMK15HM0.40			0%	0%	0.40%

Notes:
#1% volume fraction of steel fibers ≈ 78 kg/m^3.
#1% volume fraction of polypropylene fibers ≈ 9 kg/m^3.
#All concrete mixes had the same water/binder materials ratio (W/B) of 0.30.
#Superplasticizer (SP) content kept constant for all mix groups, (1% of binder material weight).

Table (7): Concrete Mix Proportions for one Cubic Meter of Fresh Concrete

Material	Quantity
Cement (OPC)	500 kg/m^3
Coarse aggregate (CA)	1125 kg/m^3
Fine aggregate (FA)	630.0 kg/m^3
Metakaolin (MK)	5%, 10%, 15%, 20% and 25% partial replacement of cement weight
Nano Metakaolin (NMK)	15% partial replacement of cement weight
Steel Fiber (SF)	0.20% and 0.40% by volume fraction
Polypropylene Fiber (PPF)	0.20% and 0.40% by volume fraction
Hybrid Mixture (HM) (75% SF and 25% PPF)	0.20% and 0.40% by volume fraction
Water	150.0 lit/m^3
High range water reducer admixture (HRWR)	4.85 kg/m^3

5. Results and Discussion of the First Stage

5.1 Effect of MK on Water of Consistency and Setting Times

Table (8) shows Water of consistency and setting times of (5, 10, 15, 20 and 25%) MK /OPC mixes compared to control OPC.

Table (8): Water of Consistency and Setting Times of (5-25%) MK /OPC Mixes Compared to Control OPC.

Mixes	OPC, %	MK, %	Water of consistency, (%)	Setting times, (min.)	
				Initial	Final
OPC (Control)	100	-	25.3	117	221
OPC+5% MK	95	5	25.6	80	211
OPC+10% MK	90	10	26.3	68	191
OPC+15% MK	85	15	26.6	62	182
OPC+20% MK	80	20	27.1	65	189
OPC+25% MK	75	25	27.6	73	202

It can be seen from table (8) that, the greater the proportion of the substitution of meta-kaolin as a partial substitute for cement, the greater the amount of water needed by the mixture to form, compared to the mixtures without nano-metakaolin. The partial replacement of Portland cement using metakaolin decreases the initial and final setting time compared to the setting time for mixtures without metakaolin.

5.2 Effect of MK on Compressive Strength

Table (9) gives the results of the compressive strength of MK/OPC mixtures, which contain the ratios 0, 5, 10, 15, 20 and 25% MK after treatment times (Water Curing) 2, 7, 14, 28, and 56 days Compared to Control OPC.

Table (9): Compressive Strength of 5 to 25% MK/OPC Mixes Compared to OPC.

Mixes	Compressive strength, (N/mm^2)						
	2 days	7 days	14 days	28 days		56 Days	
OPC (Control)	34.9	44.1	55.7	71.8	% Increase	76.4	% Increase
OPC + 5% MK	32.0	52.2	59.1	78.9	10%	84.1	10%
OPC + 10% MK	27.7	47.3	63.9	83.9	17%	90.7	19%
OPC + 15% MK	24.3	40.8	67.2	87.7	22%	95.9	26%
OPC + 20% MK	22.8	37.2	54.9	74.6	4%	86.3	13%
OPC + 25% MK	19.6	33.0	45.7	69.6	-3%	79.9	5%

The test results in table (9) showed that:

- For All MK / OPC mixtures (5-25%), a significant decrease in the compressive strength value at early ages (two days) for mixtures that contain partial substitution of MK compared to the reference mixtures. Which shows the delay in the effect of the Pozzolanic reaction until this age (two days).
- A noticeable increase in the compressive strength value at the age of (28) days for mixtures that contain partial substitution of MK compared to the reference mixtures, up to a substitution rate of (15% MK). Where the compressive strength increases at (28) days old by 10, 17, and 22% when partial replacement of Portland cement by 5, 10, and 15% metakaolin, respectively. This percentage increases to 10% & 19% & 26% at the age of (56) days.
- A significant decrease in the compressive strength value occurred at the age of (28) days for mixture containing partial substitution of MK (25%) compared to the reference mixtures.
- The best mixture that achieves the highest rate of increase in compressive strength (up to 22%) relative to the reference sample is 15% MK/OPC (After 28 days Curing). While the increase in compressive strength of the 10% MK/OPC mixture reaches 17%.

6. Results and Discussion of the Second Stage

6.1 The Effect of MK and NMK Inclusion on the Compressive Strength of Normal (Plain) Concrete

The test results of cube compressive strength at ages 7 and 28 days are presented in table (10). Table (11) shows the percentage of increase in compressive strength of concrete made with MK and NMK compared to the control plain concrete (not containing fiber).

Table (10): Cube Compressive Strength

Group no.	Concrete mix	Cube compressive strength (N/mm^2)	
		7 days	28 days
G1	MK0F0	42.1	56.1
	MK0SF0.20	48.3	66.5
	MK0PPF0.20	43.4	64.1
	MK0HM0.20	49.2	68.8
	MK0SF0.40	50.3	69.2
	MK0PPF0.40	47.5	67.3
	MK0HM0.40	53.3	72.3
G2	MK10F0	49.4	68.9
	MK10SF0.20	50.9	73.2
	MK10PPF0.20	44.8	68.8
	MK10HM0.20	51.9	73.9
	MK10SF0.40	54.7	76.95
	MK10PPF0.40	50.4	72.8
	MK10HM0.40	58.7	82.8
G3	MK15F0	52.2	72.5
	MK15SF0.20	53.1	76.5
	MK15PPF0.20	46.8	70.8
	MK15HM0.20	53.2	77.0
	MK15SF0.40	56.4	80.1
	MK15PPF0.40	52.6	77.2
	MK15HM0.40	60.9	86.1
G4	MK20F0	49.1	67.9
	MK20SF0.20	50.6	72.3
	MK20PPF0.20	44.6	67.4
	MK20HM0.20	51.1	73.9
	MK20SF0.40	54.4	76.8
	MK20PPF0.40	49.9	71.9
	MK20HM0.40	58.2	80.0
G5	NMK15F0	56.9	78.4
	NMK15SF0.20	62.6	87.5
	NMK15PPF0.20	52.9	80.4
	NMK15HM0.20	62.7	89.6
	NMK15SF0.40	67.1	95.1
	NMK15PPF0.40	62.8	91.3
	NMK15HM0.40	71.4	98.3

Table (11): % Increase in Cube Compressive Strength of Specimens Made with MK and NMK Compared to Plain Concrete (Not Containing Fiber)

Group no.	Concrete mix	% Increase in compressive Strength	
		7 days	28 days
G1	MK0F0	0.00%	0.00%
G2	MK10F0	17.33%	22.82%
G3	MK15F0	24.0%	29.23%
G4	MK20F0	16.63%	21.0%
G5	NMK15F0	35.15%	39.75%

It was observed from table (11) that an enhancement of about (22.82%, 29.23% and 21.0%) was observed compared to the control specimen at MK content of (10%, 15% and 20%) respectively. As for the NMK at the same age (28 days), a significant increase of about 39.75% compared to the control specimen was observed at 15% of NMK content.

6.2 The Effect of MK and NMK Inclusion on the Compressive Strength of Fibrous Concrete

6.2.1 Steel Fiber Reinforced Concrete (SFRC)

An enhancement of about (23.35%, 37.17%, 42.78% and 36.9%) was observed compared to the control plain concrete specimen (**MK0SF0**) at MK content of (0%, 10%, 15% and 20%) respectively. As for the NMK at the same age (28 days), significant increase in compressive strength of about 69.52% compared to the control plain concrete specimen (**MK0SF0**) was observed at 15% of NMK content.

6.2.2 Hybrid Mixture Fiber Reinforced Concrete (HMFRC)

An enhancement of about (28.88%, 47.6%, 53.5% and 42.6%) was observed compared to the control plain concrete specimen (MK0F0) at MK content of (0%, 10%, 15% and 20%) respectively. The percentage of increase in compressive strength of specimen with zero content of SCMs materials (28.88%) reflects only the enhancement achieved by the presence of 0.40% HMF in the mixture over the control plain concrete specimen. As for the NMK at the same age (28 days), significant increase in compressive strength of about 75.22% compared to the control plain concrete specimen (MK0F0) was observed at 15% of NMK content. The observed increase of compressive strength is a result of the high pozzolanic activity of NMK, and the presence of 0.40% HMF in the mixture.

6.3 The Effect of MK and NMK Inclusion on the Split Tensile Strength of Normal (plain) Concrete, Effect of SCMs over Plain Concrete

Table 12 shows the variation in concrete tensile strength made with MK and NMK at 28 days.

Table (12): Cylinder Split Tensile Strength

Group no.	Concrete mix	Cylinder Split tensile strength (N/mm^2)
		28 days
G1	MK0F0	**4.7**
	MK0SF0.20	4.95
	MK0PPF0.20	4.92
	MK0HM0.20	5.0
	MK0SF0.40	5.28
	MK0PPF0.40	5.08
	MK0HM0.40	5.32
G2	MK10F0	**4.92**
	MK10SF0.20	5.07
	MK10PPF0.20	5.07
	MK10HM0.20	5.1
	MK10SF0.40	5.58
	MK10PPF0.40	5.28
	MK10HM0.40	5.67
G3	MK15F0	**5.13**
	MK15SF0.20	5.57
	MK15PPF0.20	5.13
	MK15HM0.20	5.42
	MK15SF0.40	5.83
	MK15PPF0.40	5.53
	MK15HM0.40	5.93
G4	MK20F0	**4.82**
	MK20SF0.20	5.18
	MK20PPF0.20	4.98
	MK20HM0.20	5.07
	MK20SF0.40	5.48
	MK20PPF0.40	5.22
	MK20HM0.40	5.47
G5	NMK15F0	5.56
	NMK15SF0.20	6.33
	NMK15PPF0.20	5.72
	NMK15HM0.20	6.68
	NMK15SF0.40	6.48
	NMK15PPF0.40	6.13
	NMK15HM0.40	7.29

Table (13) shows the percentage of increase in split tensile strength of concrete made with MK and NMK compared to the control plain concrete specimen (MK0F0)

Table (13): The percentage of increase in cylinder split tensile strength of specimens made with MK and NMK compared to the control plain concrete specimen (MK0F0)

Group no.	Concrete mix	% increase in split tensile strength
		28 days
G1	MK0F0	0.00%
G2	MK10F0	4.7%
G3	MK15F0	9.15%
G4	MK20F0	2.6%
G5	NMK15F0	18.3%

An enhancement of about (4.70%, 9.15% and 2.6%) was observed compared to the control specimen at MK content of (10%, 15% and 20%) respectively. As for the NMK at the same age (28 days), a significant increase of about 18.3% compared to the control specimen was observed at 15% of NMK content.

6.4 The Effect of MK and NMK Inclusion on the Split Tensile Strength of Fibrous Concrete

6.4.1 Steel Fiber Reinforced Concrete (SFRC)

An enhancement of about (12.34%, 18.72%, 24.04% and 16.6%) was observed compared to the control plain concrete specimen (MK0F0) at MK content of (0%, 10%, 15% and 20%) respectively. As for the NMK at the same age (28 days), a significant increase in split tensile strength of about 37.87% compared to the control plain concrete specimen (MK0F0) was observed at 15% of NMK content.

6.4.2 Polypropylene Fiber Reinforced Concrete (PPFRC)

An enhancement of about (8.1%, 12.34%, 17.66% and 11.64%) was observed compared to the control plain concrete specimen (MK0F0) at MK content of (0%, 10%, 15% and 20%) respectively. As for the NMK at the same age (28 days), a significant increase in split tensile strength of about 30.43% compared to the control plain concrete specimen (MK0F0) was observed at 15% of NMK content.

6.4.3 Hybrid Mixture Fiber Reinforced Concrete (HMFRC)

An enhancement of about (13.2%, 20.64%, 26.17% and 16.38%) was observed compared to the control plain concrete specimen (MK0F0) at MK content of (0%, 10%, 15% and 20%) respectively. As for the NMK at the same age (28 days), a significant increase in split tensile strength of about 55.11% compared to the control plain concrete specimen (MK0F0) was observed at 15% of NMK content.

6.5 Effect of 0.40% fiber content Inclusion on the split tensile Strength of Normal (plain) Concrete Compared to Control Specimen (MK0F0)

The cylinder split tensile strength and the percentage of increase in cylinder split tensile strength of plain concrete made with different types of fiber compared to the control plain concrete specimen (MK0F0) is shown in table (14) for specimens made with (0.40%) volume fraction of different types of fiber.

Table (14): Cylinder split tensile strength and the percentage of increase in cylinder split tensile strength of specimens made with different types of fiber (v_f = 0.40%) compared to plain concrete specimen (MK0F0)

Concrete mix	Cylinder Split Tensile Strength (N/mm^2)	
	28 days	% Increase
MK0HM0 (control mix)	4.7	0.0
MK0SF0.40	5.28	12.34
MK0PPF0.40	5.08	8.1
MK0HM0.40	5.32	13.2

Because of the high elastic modulus of steel fiber and the low elastic modulus of polypropylene fiber work in perfect combination (HMF) and resulted in higher split tensile strength compared to SFRC or PPFRC specimens at the same volume fraction.

6.6 Effect of different types of fiber incorporating at v_f = 0.40% compared to the control specimen (NMK15F0)

The cylinder split tensile strength and the percentage of increase in cylinder split tensile strength of concrete containing 15% NMK made with different types of fiber compared to the control specimen (NMK15F0) is shown in table (15) for specimens made with (0.40%) volume fraction of different types of fiber.

Table (15): Cylinder split tensile strength and the percentage of increase in cylinder split tensile strength of specimens containing 15% NMK made with different types of fiber (v_f = 0.40%) compared to the control specimen (NMK15F0)

Concrete mix	Cube compressive strength (N/mm^2)	
	28 days	% Increase
NMK15F0 (control mix)	5.56	0.0
NMK15SF0.40	6.48	21.3
NMK15PPF0.40	6.13	16.45
NMK15HM0.40	**7.29**	**31.11**

An enhancement of about (21.3%, 16.45%, and 31.11%) was observed compared to the control specimen (NMK15F0) at fiber type of (SF, PPF and HMF) respectively.

7. Conclusion

7.1 Conclusions Based on the First Stage

Based on the experimental results of the first stage, the following concluding remarks were drawn:

1. The metakaolin content of Portland cement decreases with it the initial and final setting time relative to the setting time of metakaolin-free Portland cement (control) up to 15% MK, after which the setting time begins to rise slightly to 25% MK.
2. For All MK / OPC mixtures (5-25%), a significant decrease in the compressive strength value at early ages (2 days) for mixtures that contain partial substitution of MK compared to the reference mixtures. Which shows the delay in the effect of the Pozzolanic reaction until this age (2 days).
3. A noticeable increase in the compressive strength value at the age of (28) days for mixtures that contain partial substitution of MK compared to the reference mixtures, up to a substitution rate of (15% MK). Where the compressive strength increases at (28) days old by 10, 17, and 22% when partial replacement of Portland cement by 5, 10, and 15% MK, respectively. This percentage increases to 10% & 19% & 26% at the age of (56) days.
4. The best mixture, which achieves the highest percentage of increase in compressive strength after (28) days (22%), is the one that contains partial replacement of cement with MK at a percentage of (15%).

7.2 Conclusions Based on the Second Stage

Based on the experimental results of the Second stage, the following concluding remarks were drawn:

5. The optimum dose of MK was found to be 15% (by cement weight) in all test ages. The increase in concrete compressive strength was (24.0% and 29.23%) at 7 and 28 days respectively. This is a very encouraging result as the use of metakaolin as supplements in concrete up to 15% will reduce the cost of cement and the negative environmental pollution being experienced as a result of cement production.
6. The addition of NMK to the mixture resulted in a significant increase in compressive strength especially at early ages (i.e., 7 days) compared to MK concrete or plain concrete. The increase of concrete compressive strength at 15% replacement was (35.15%, 39.75%) at 7 and 28 days respectively.
7. The addition of different percentages of SF, PPF, and HMF to normal concrete in the presence of SCMs materials improved the compressive and split tensile strength. The gain in compressive strength is improved depending on the replacement level of cement by MK. The combined effect of fiber and MK showed that the optimum dose of MK found to be 15% (by cement weight) for various volume fraction of fiber in all test ages.
8. The addition of NMK to the mixture resulted in a significant increase in compressive and split tensile strength especially at early ages. It is found that partial replacement of cement with NMK has the greatest influence on the compressive and split tensile strength of

concrete for various volume fraction of fiber in all test ages. The combined effect of fiber and NMK showed an increase of compressive strength at 15% replacement.

9. Partial replacement of cement with NMK has a greater influence on the split tensile strength of concrete. The increase of concrete split tensile strength at 15% replacement was (18.30%) when compared to the control specimen at 28 days.
10. In general, adding fibers to concrete mixtures, as well as partial substitution of cement with MK and NMK, resulted in a significant improvement in the mechanical properties of the concrete samples under study. It was found that the amount of improvement in the mechanical properties of concrete depends on the type of fibers, as well as the proportions of cement replacement with complementary materials.
11. Based on the foregoing, it is clear that fiber-reinforced concrete mixtures using nano-meta kaolin as a partial replacement of cement can be successfully used as a construction material in pouring reinforced concrete beams.

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