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SUSTAINABLE PERFORMANCE OF REACTIVE POWDER CONCRETE BY USING NANO META KAOLIN

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Abstract: This investigation aimed to study the sustainable effect of Nano Meta Kaolin (NMK) on some properties of reactive powder concrete. In this study, Reactive powder concrete (RPC) specimens were designed, prepared and cured for different ages (7, 28 and 60) days. The suggested specimens dimensions consist of cubes with (50mm), cylinders with (100×200 mm) and cylinders with (150×300 mm), to study compressive strength, splitting indirect tensile strength, and modulus of elasticity with varied Nano Meta Kaolin content (0, 2%, 3.5% and 5%) by weight of cementitious materials as an addition. All specimens were cured with hot water treatment (60 Cº) for 12 hours, and then put in normal water until testing day. It was found that the compressive strength of concrete with the Nano Meta Kaolin higher than the reference concrete, and also the same trend was observed for the splitting tensile strength. improvement in the compressive strength at 28 days when using (2,3.5, 5%) Nano Meta Kaolin has been about (5-15%), While the improvement in the splitting tensile strength was (3-7%), and the improvement in modulus of elasticity was (10-26%).

Keyword: *Sustainable, Reactive concrete, Nano Meta kaolin, Mechanical properties.*

الاداء المستدام للخرسانة ذات المساحق الفعالة الحاوية على النانو ميتا كاؤلين

الخلاصة : يهدف البحث لدراسة تأثير الاستدامة لمادة النانو ميتا كاؤلين على بعض الخصائص لمادة الخرسانة ذات المساحيق الفعالة. تم تصميم وتحضير ومعالجة نماذج الخرسانة ذات المساحيق الفعالة بأعمار مختلفة(60,28,7) يوم. النماذج المقترحة شملت مكعبات ذات ابعاد 50 مم وأسطوانات بأبعاد100*200مم واسطوانات بأبعاد 150* 300مم،لدراسة مقاومة الانضغاط ،معاير الانشطار ومعاير المرونة الاستاتيكي .تم استخدام نسب مختلفة من الميتا كاؤلين (2,0%،3.5%،5%)من وزن المواد السمنتيه كمادة اضافية .تم معالجة جميع النماذج بالماء الحار وبدرجة حرارة 60 درجة سليزيه ولمدة 12 ساعة، ثم وضعت بالماء بدرجة حرارة الغرفة حتى الفحص. وجد ان التحسن بقيمة مقاومة الانضغاط عند استخدام النانو ميتا كاؤلين بنسبة (2-5%) بعمر 28 يوم كانت بحدود (5-15%)،بينما كان التحسن بقيمة الانشطار (3-7%) والتحسن في معاير المرونة الاستاتيكي كان (10-26%).

1. Introduction

Reactive powder concrete(RPC) is one of the most promising types of concrete, which has been developed in the last decade. The efficiency of RPC is particularly dependent on its density. This can be maximized by optimizing the particle packing, thus resulting in ultra-high consolidation of the concrete matrix. The optimized particle packing can be obtained through an almost 'perfect' grain size distribution, by

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incorporating a homogeneous gradient of fine and coarse particles in the mixture. In this scope, the use of Nano materials, as pozzolanic additions, is highly effective. In fact, due to their extremely small size, nanomaterials can fill the voids between cement and silica fume particles, leading to higher packing level and also generating a denser binding matrix, with more calcium silicate hydrate (C-S-H). Thus, this causes a significant improvement on both durability and mechanical properties of concrete *(Ghafari et al., 2013).*

In last two decade, the use of metakaolin (MK) grew the interest for this aim. Metakaolin is a thermally activated alumina silicate material given by calcaining kaolin clay with a bout of 700–850 ºC temperature, along with being a valuable pozzolanic material. Kaolin may be notably impure from natural sources, even after beneficiation. Through heating, MK was reduced to Nano scale by grinding it with in a high speed ball grinding mill *(Morsy et al., 2010).* The improvements in the properties of hardened cement composites due to the addition of Nano metakaolin particles can be explained by two mechanisms, the first is the chemical effect, which works on two levels : accelerating the dissolution of C_3S and rapid formation of the CSH phase in the cement paste; and the pozzolanic reaction of silica with calcium hydroxide (CH) generates additional CSH gel in the final stages. The second mechanism is the physical effect; NC can fill the remaining voids in young and partially hydrated cement paste, which leads to a denser and more compact structure *(Aly et al., 2011).*

2. Objectiv of the Reserch

Investigating the effect of Nano Metakaolin the mechanical properties (compressive strength, splitting tensile strength, and modulus of elasticity) of RPC for ages(7-60)days

3. Expermel Work

3.1. *Materials*

3.1.1. *Cemen.*

Ordinary Portland cement (OPC) manufactured in Iraq with trade mark of (Almas) . The oxide composition of the cement is shown in Table (1).The results show that the cement is with the requirements of IQS No.5/1984.

Table (1):- Chemical composition and main compounds of the cement*

Compound Composition	*Percentage By Weight*	*Limit of Iraqi Specification No.5/1984*
Lime (CaO)	*61.52*	-
Silica (SiO_2)	*21.67*	-
Alumina (Al_2O_3)	*5.33*	-
Iron oxide (Fe_2O_3)	*3.31*	-
Magnesia (MgO)	*2.97*	*5.0 (max)*
Sulfate (SO_3)	*2.45*	*2.8 (max)*
Loss on ignition (L.O.I.)	*3.41*	*4.0 (max)*
Insoluble residue I.R.	*0.91*	*1.5 (max)*
Lime saturation factor (L.S.F.)	*0.86*	*(0.66-1.02)%*

** Chemical tests were conducted by the environmental laboratory in University of Babylon*

3.1.2. *Aggregate*

Al-Eakhadir natural sand was used as the fine aggregate throughout this research. It was tested to determine the grading and other Physical and Chemical properties. The results show that the fine aggregate grading is within the requirements of the Iraqi Specification (IQS No.45/1984).

For RPC, using very fine sand with maximum size 600μm. The sand that adopted was separated by sieving. Tables (2) and (3) illustrate the sieve analysis of the original and the separated fine sand respectively.

Table (2):- Grading of the fine sand compared with the requirements of the Iraqi Specifications No.45/1984.(Zone 3)

Sieve Size mm	*Cumulative Passing %*	*Iraqi Standards (45/1984) as in (zone 3)*
9.5	100	100
4.75	97	90-100
2.36	92	85-100
1.18	88	75-100
0.600	71	60-79
0.300	30	12-40
0.150	10	0-10

Table (3): Grading of separated sand compared with the requirements of the Iraqi Specifications No.45/1984

Sieve Size mm	*Cumulative Passing%*	*Limits of Iraqi specification No.45/1984, zone 4*
9.5	100	100
4.75	100	95-100
2.36	100	95-100
1.18	100	90-100
0.600	100	80-100
0.300	39	15-50
0.150	9	0-15

3.1.3. *Silica fume*

Densified Micro silica fume from (Leyco Chem LEYDE Iraq) Company in Bagdad under commercial name (LEYCO®-ACC Micro silica/Grade 85D)(Company Information).It has been used as a mineral admixture added to the mixture of the research.

After many trial mixes the replacement of 23 % by weight of cement by silica fume was considered the best percent to get the target strength in this research. The chemical composition of silica fume used in this investigation is shown in Table (4), while the physical requirements are listed in Table (5).

Table (4):- Chemical analysis of Silica Fume*

Oxide composition	*Oxide content %*	*ASTM C-1240 limitations*
SiO_2	87.6	≥ 85
Al_2O_3	0.36	-
Fe_2O_3	1.16	-
Na_2O	0.05	-
K_2O	0.07	-
CaO	1.25	-
MgO	2.45	-
SO_3	0.9	-
L.O.I.	3.8	≤ 6.0
Moisture content	0.8	≤ 3.0

* manufacture properties

Table (5):- Physical properties of Silica Fume used*

Physical properties	Silica Fume	Limit of specification ASTM C-1240
Percent retained on 45µm (No.325) sieve, max, %	7	≤ 10
Pozzolanic Strength Activity Index with Portland cement (accelerated curing 7 days), min. percent of control	129	≥ 105
Specific surface, min, (m2/g)	21	≥ 15

*Manufacturer Properties

3.1.4. *High-range water reducing admixture (superplasticizer)*

Sika® ViscoCrete® -5930 is a Superplastiiser for concrete meeting the standard requirements of ASTM C494/C494M-02 type F&G. It is High Performance Super plasticizer Concrete Admixture, It is imported from Sika company in Egypt .Table (6) shows the main properties of SikaViscocrete-5930.

Table (6) :- Technical description of sikaviscocrete-5930 *

Basis	Aqueous solution of modified polycarboxylate
Boiling	100°C
Hazardous Decomposition Products (Hazardous Reactions)	No hazardous reactions known.
Odor	None
Appearance	Turbid liquid
Color	Turbid liquid
Specific Gravity	1.08 ± 0.005
pH	7-9
Labeling	No hazard label required
Chloride content	None
Toxicity	Non-Toxic under relevant health and safety codes
Storage	Protected from direct sunlight and frost at temperatures between + 5°C and + 35°C.

3.1.5. *Steel fibers*

Straight short Steel fibers manufactured by *the Ganzhou Daye Metallic Fibres Co., Lt, China.*, were used throughout the experimental program, Chemical composition and Properties of steel fibers shown in Tables (7) and (8). It has a diameter of (0.2 mm) and a straight length of (13mm), (L/d = 65).

Table (7):- Chemical composition of steel fibers.*

Chemical Composition	Composition (%)
Carbon (C)	0.80
Manganese (MN)	0.75
Phosphorus (P)	0.035
Sulfur (S)	0.035
Silicon (Si)	0.30

*Manufacturer Properties

Table (8):- Properties of the used Steel Fibers

Property	*Specifications*
Type	WSF 0213
Surface	Brass coated
Density	7860 Kg/m3
Tensile Strength	Minimum 2300MPa
Form	Straight
Melting Point	1500°C
Average length	13 mm
Diameter	0.2mm±0.05mm
Aspect ratio (Lf/Df)	65

3.1.6. *Nano meta kaolin (NMK)*

Nano Meta Kaolin was imported from *(English Indian Clays Limited (EICL)*; its local name is *Metacon Metakaolin*, its physical and chemical properties are shown in Table (9), (10) and (11) respectively.

Table (9):- Physical properties of Nano Metakaolin*

Appearance	*Off-white*
Lime reactivity (Chapelle test)mg/gm	740 – 1,000
Specific gravity	2.6
Blaine value (cm^2/g)	25000
Loss on ignition	0.5 – 1.5%
pH (10% solids)	4.0 – 5.0
Bulk density, kg/lt	0.4 – 0.5
SO_3 %	0.05

*Manufacture properties

Table (10):- Chemical analysis of Nano Metakaolin (Mass%)

Oxide composition	Pozzolan class N	NMK
SiO_2+Al_2O_3+Fe_2O_3, min.%	70	96.6-101.2
Loss on ignition, max. %	10	0.5-1.5
SO_3, max. %	4	0.05

*Given by manufacture.

Table (11):- Chemical requirements of pozzolan ASTM C618

Chemical Composition	Results
Al_2O_3	44.0 – 46.0
TiO_2 (max)	0.65
MgO (max)	0.03
K_2O (max)	0.03
SiO_2	52.0 – 54.0
Fe_2O_3	0.60 – 1.20
CaO (max)	0.09
Na_2O (max)	0.10

*Given by manufacture.

3.2. *Concrete Prepertion*

Reactive powder concrete with the various percent of NMK (2, 3.5, 5%) were used in this investigation(*Masar 2015*) . Table (12) gives the details and mix design of all mixes used in this study. The concrete was prepared by mixing method as follows: super plasticizer dosage is dissolved in water in small mixer with light speed for 2 minute, then add the NMK to them and mixing them well for 3 minute, Adding silica fume to (water + SP + NMK) and mixing for 3 minute.

Finally adding cement to mix and then adding the fine aggregate to the mixer until the mixture becomes homogeneous, then adding steel fiber. The molds used in this study were cubes of 50 (mm) size and cylinders of(100 * 200 mm), (150 * 300 mm). The samples were kept wet in molds, and then cured in hot water (60 ºC) for 12 hours and then put in tap water (21 ºC) until testing age, as shown in Figure (1).

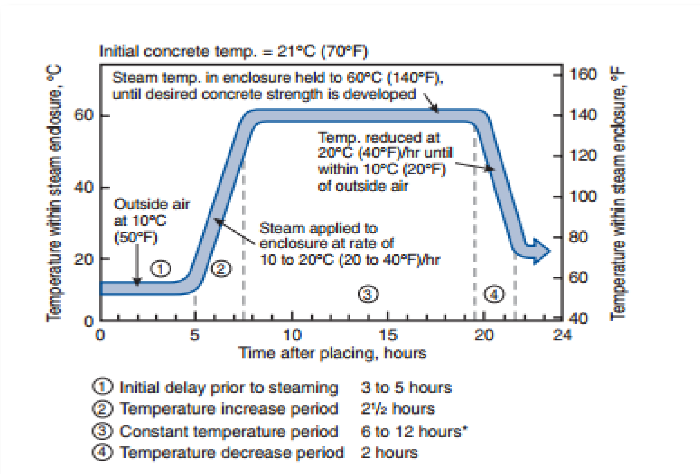


Figure (1):- A typical atmospheric steam-curing cycle (ACI C517,1992)

Table (12): RPC mix designations

Mix	Details	Cement (kg/m)	SF (kg/m)	NMK (kg/m^3)*	Fine aggregate (kg/m^3)	Steel fiber % by volume	w/c ratio	Sp % *	Flow mm ASTM C230&AS TB C1437
M1	0% NMK	898	202	0	1000	1	0.175	0.5	95
M2	2% NMK	898	202	22	1000	1	0.175	0.5	100
M3	3.5% NMK	898	202	38.5	1000	1	0.175	0.56	92
M4	5% NMK	898	202	55	1000	1	0.175	0.6	91

4.Testing

4.1. *Compressive Strength*

Based on the ASTM C109/ C109 M (2004), the compressive strength test was carried out on 50 mm cubes using a hydraulic compression machine of (2000) kN at a loading rate of 0.9 kN per second. The average of three cubes was adopted for each test and was conducted at ages of (7, 28, 60) days.

4.2. *Splitting Tensile Strength*

Splitting tensile strength has been determined by testing standard cylinders of (100×200) mm for every mix depending on ASTM C 496-2004 specification. Two thin plywood strips were placed between the specimen and both the upper and the lower bearing blocks of testing machine which was a hydraulic compression machine of 2000 KN. The average of two cylinders was taken at ages of (7, 28, 60) days. The splitting tensile strength is calculated by the following equation:

$$\boldsymbol{fsp}=\mathbf{2}\boldsymbol{P}/\boldsymbol{\pi}dl \text{ - - - - } (1)$$

Where:
F_{sp}: Splitting tensile strength, (MPa)
p: Max. applied load indicated by the testing machine, (N)
d: Cylinder diameter, (mm)
l: Cylinder length, (mm)

4.3. *Static Modulus of Elasticity*

This test was carried out on 150×300 mm cylindrical specimens. The 40% of ultimate compressive strength of concrete specimen was applied on the concrete cylinders to perform the elastic modulus test as specified by ASTM C469-2002 . The average of two cylinders was taken at each test. The modulus of elasticity is calculated, as follows:

$$E = \frac{S_2 - S_1}{\varepsilon_2 - 0.00005} \times 10^{-3} \qquad \text{……….(2)}$$

where:
E : static modulus of elasticity, (MPa).
S_2 : stress corresponding to 40% of ultimate load, (MPa).
S_1 : stress corresponding to a longitudinal strain (0.00005), (MPa).
e_2 : longitudinal strain produced by stress, S_2.

5. Results and Discution

5.1.*Compressive Strength*

In Fig. (2), it can be seen that the pozzolanic materials (NMK) when used as addition material by cement weight in concrete improved the compressive strength, The compressive strength increased with addition of NMK for all mixes and at all ages due to ultrafine of Nano metakaolin particles which filled the pores in mixture hence given denser microstructure. The pozzolanic reaction of Nano metakaolin with free lime released through hydration process produce additional calcium silicate hydrate that gets deposited in pore system hence resultant in the development of mechanical properties *(Morsy et al., 2010).*

The increase percentage are (5.63, 5.27, & 7.89%) for ages (7 , 28 & 60) days respectively when using 2% NMK. While when using 3.5% NMK this increase are (13.43, 12.92, & 14.62%) for ages (7, 28 & 60) days respectively. Finally the increase are (16.10%, 15.45% and 17.14 %) when using 5% NMK for ages (7 ,28 & 60) days respectively . This comes to agree with what mentioned in (Alwash, 2013) and (Gu¨neyisi et al., 2007) who studied the influence of metakaolin on compressive strength at age 1, 3, 7, 28, 90, and 120 days with different replacement levels of metakaolin and showed that the MK provided positive effect on the strength of concrete generally starts at early ages and also noticeable increase in the strength was observed at later ages .

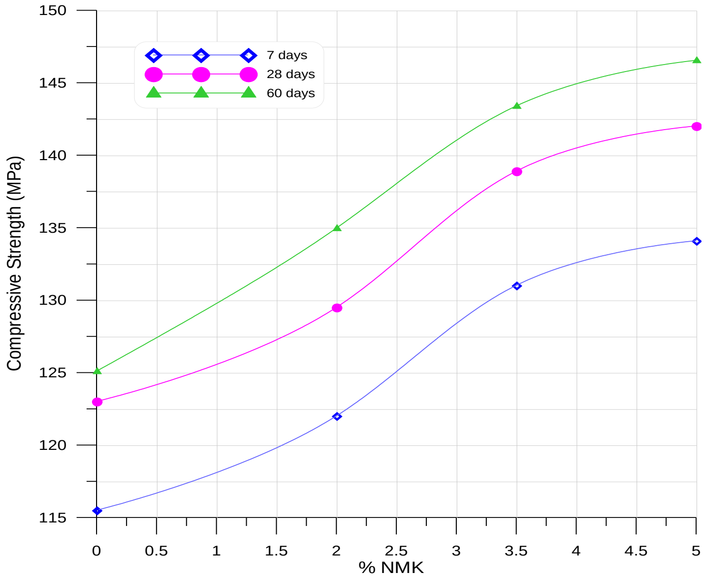


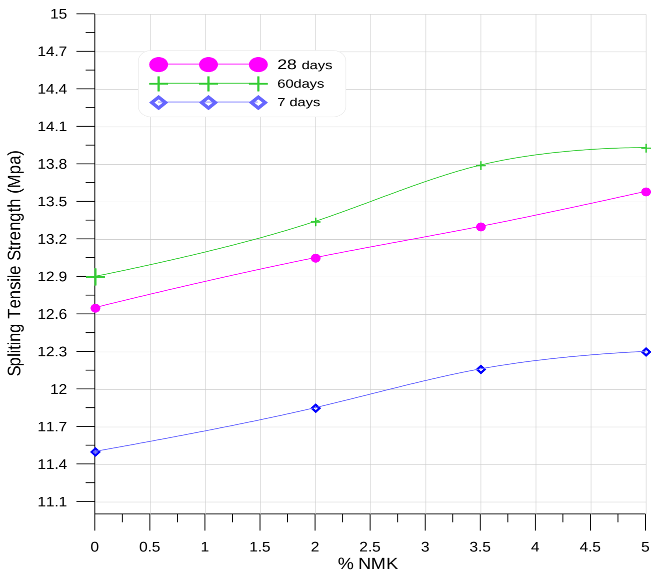
Figure (2):- Effect of Nano Metakaolin content on compressive strength

5.2. *Splitting Tensile Strength*

Fig. (3) shows the tensile strength results of all mixes containing different NMK ratios. It is observed that the tensile strength of NMK concrete increases as the NMK ratio increases.

The higher percent of increase in tensile strength is 5% of NMK when compared with the reference mix by (6.95%, 7.35% and 7.98%) at (7, 28 & 60) days after hydration respectively, while 3.5% NMK when compared with the reference mix by (5.73%, 5.77% and 6.89%) and 2% NMK by (3.04%, 3.16% and 3.41%) at (7, 28 & 60) days after hydration respectively.

These results are due to the pozzolanic reaction which reduces the micro cracking and strengthen the transition zone through the pore size and grain size refinement processes, since the Nano Metakaolin accelerated the rate of hydration by improving the quality of the interfacial zone (ITZ) by the precipitation of stronger and smaller calcium silicate hydrate gel. That is in agreement with (Gu¨neyisi et al., 2007).



Figure(3):- Effect of Nano Metakaolin content on splitting tensile strength

5.3. *Static Modulus of Elasticity*

It was clear from Fig. (4) that the modulus of elasticity increases with adding Nano Meta Kaolin for all mixes and at all ages. The increase percentage are (10.5, 12.27& 15.87%) for ages (7 ,28 ,60 & 90) days respectively when using 2% NMK. While when using 3.5% NMK this increase are (15.05, 18.25 , & 23.2%) for ages (7 ,28 &60) days respectively . Finally the increase are (17.5, 21.88 & 26.98 %) when using 5% NMK for ages (7 ,28 ,60 & 90) days respectively. This behavior of the mixes is mainly attributed to the influence of the mineral admixtures (NMK) on the interfacial zone and the bond in composite material. The elastic behavior of concrete depends on the bond strength, density of the interfacial zone, and on densities and void contents of the concrete. In general, capillary voids, micro cracks, and oriented calcium hydroxide crystals are relatively more common in the interfacial transition zone than in the bulk matrix.

Therefore, they play an important part in determining the stress-strain relations in concrete. The quality of the bond between the cement paste and aggregate is of importance and may affect the value of the modulus of elasticity of concrete when the bond is particularly strong, as the case in high performance concrete *(Naji, 2011).* The result showed that the increasing in compressive strength leading to an increase in modulus of elasticity, for example the lowest compressive strength 122.01 MPa has the lowest modulus of elasticity 49.87 GPa, whereas the highest compressive strength 146.55 MPa has the greatest modulus of elasticity 61.59 GPa. This conclusion is consistent with (Neville, 1995).

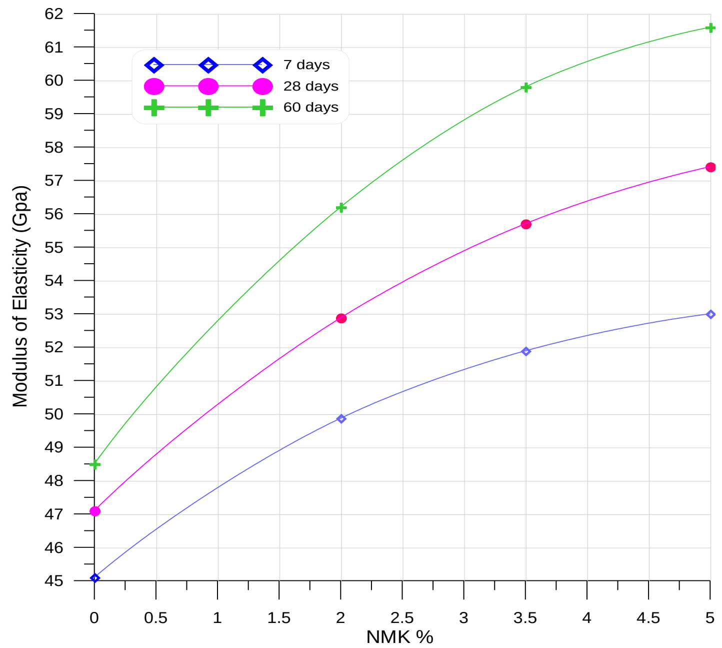


Figure (4):- Effect of Nano Metakaolin content on modulus of elasticity.

6. Conclusions

Based on the experimental studies presented in this paper, the following conclusions can be drawn:

- The addition of Nano Meta Kaolin (NMK) enhanced the sustainable properties of reactive powder concrete.
- The enhancement of compressive strength was (5.27, 12.92, & 15.45%) at 28 days for (2, 3.5, &5%) addition of Nano Meta Kaolin (NMK) respectively.
- The enhancement of splitting tensile strength was (3.16, 5.77, &7.35%) at 28 days when using (2, 3.5, &5%) Nano Meta Kaolin (NMK) respectively.
- The improvement in modulus of elasticity was (12.27%, 18.25 %, &21.88) at 28 days when using (2, 3.5, &5%) Nano Meta Kaolin (NMK).

7. Refrences

1. *Ghafari E. , Costa H., Júlio E., Portugal A., and Luisa D. (2013),* "*The effect of Nano Silica addition on flowability, strength and transport properties of ultra-high performance concrete*", *journal of Materials and Design* vol. (59) PP.(1-9).
2. *Morsy M. S., Alsayed S. H. and Aqel M. (2010),* "*Effect of Nano-clay on mechanical properties and microstructure of ordinary portland cement mortar*" *International Journal of Civil & Environmental Engineering,* Vol. (10), No. (01).
3. *Aly M., Hashmi M. S., Olabi A. G., Messeiry M., Hussain A. I. and Abadir E. F. (2011)*, "*Effect of nano-clay and waste glass powder on the properties of flax fiber reinforced mortar*" *ARPN Journal of Engineering and Applied Sciences*_Vol. (6), NO. (10).
4. *Iraqi Specification No.45/(1984),* "*Aggregate from natural sources for concrete and construction*", *Ministry of Planning, Central Organization for Standardization and Quality Control.*
5. *ASTM C 109/C 109M (2004)*, "*Test method for compressive strength of hydraulic cement mortars using (50mm) cube specimens*", *Annual Book of ASTM Standards,* Vol. (04-02)PP.1-23
6. Masar H.M. *(2015),* "*Mechanical Properties of Reactive Powder Concrete with High reactivity Nano Meta Kaolin* ", *M.SC. Thesis, Babylon University, Civil Dept.. PP.136*
7. Alwash J. J. (2013), ―self compacting concrete incorporating rice husk ash and metakaolin‖, AL-Qadisiya Journal For Engineering Sciences ,Vol. (6), .No (2).
8. Gu¨neyisi E., Gesog˘lu M., and Mermerdas K.(2007), ‖ *Improving strength, drying shrinkage, and pore structure of concrete using metakaolin*‖, Materials and Structures.Vol.7-06 .
9. ACI Committee 517 *(1992), "State of the art on accelerating curing of concrete at atmospheric pressure*", *Manual of Concrete Practice, part 5,* PP. 1-20.
10. ASTM C496 *(2004), "Standard test method for splitting tensile strength for cylindrical concrete specimens*", *American Society for Testing and Materials*, PP 1-5
11. ASTM C469 *(2002), "Standard test method for static modulus of elasticity and poisson's ratio of concrete in compression", American Society for Testing and Materials*.
12. Naji Z.H. (2011*),* "*The effect of Nano Meta Kaolin material on some properties of concrete*", *M.SC.Thesis, Technology University, Building and construction. PP.129.*
13. Neville A. M. (1995), *"Properties of concrete"*, Five, and Final Edition, Wiley, New York and Longman, London.PP.844