

## **INVESTIGATING THE IMPACT OF EMPLOYING NANOTECHNOLOGY IN HERITAGE BUILDING RESTORATION (EGYTIAN ENGINEERS SYNDICATE)**

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### **ABSTRACT**

In terms of the importance of restoring heritage buildings in Egypt, this research was initiated with the objective of evaluating the effect of using investigating the impact of employing nanotechnology during rehabilitation on the concrete mechanical and physical properties, where Engineering Syndicate Building, in Ramses Square, was taken as a case study. A research methodology was planned to encompass theoretical, experimental, analytical and inferential investigations. Throughout the theoretical investigation, literature in the field of restoring heritage buildings and nanotechnology were assembled and scrutinized. During the experimental investigation, nanoparticles mixes were produced (i.e. Nano Calcium carbonate (CaCO<sub>3</sub>) and Nano kaolin (NK)). In addition, hybrid nanoparticle mixes, with different proportions of nano-CaCO<sub>3</sub> and NK, were obtained. For comparison purposes, a reference mix was prepared. Furthermore, the impact of implementing nanoparticles, with different proportions, on concrete mechanical so as physical properties was examined. In addition, employing such mixes in old concrete restoration was investigated. All through the analytical investigation, the results were analyzed and interpreted. During the inferential investigation, conclusions so as recommendations were inferred. The results indicated that adding nanoparticles reduced the concrete

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workability and its compressive strength, in comparison to the reference mix. Moreover, the results designated that the suitable amount of the nano-CaCo<sub>3</sub> and NK nanoparticles were 1% and 5%, respectively. On the other hand, the hybrid nanoparticle proper amount was 0.5% for nano-CaCo<sub>3</sub> and 4.5% for NK. This proportion increased the hardening; achieved a better compressive strength so as adhesion to heritage building concrete and enhanced water permeability, in comparison to the reference mix. Innovative about this study is prioritizing the suitable nanoparticles proportions to ensure the efficient performance of concrete in heritage building restoration.

**Key words:** Heritage Building – Restoration - Nanoparticles – Hybrid

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## INTRODUCTION

Heritage buildings are of significant historical and social value. Accordingly, Egypt prioritized the restoration of heritage buildings, where unconventional rehabilitation due to the significant environmental considerations. In the same context, Egypt is praised to have promising engineering experience in such a field.

The problem that faced the restoration process is that repairing heritage buildings with traditional concrete increased the maintenance process interval, which increases the total cost. In addition, the obtained restoration standard is not acceptable.

This raised the importance of employing innovative restoration material during rehabilitating heritage buildings. Accordingly, this study was commenced with the objective of investigating the impact of implementing nanotechnology, during rehabilitating heritage buildings, on the concrete mechanical so as physical properties.

Consequently, all through the theoretical study, literature in the field of heritage building restoration and nanotechnology were investigated and comprehended, from which it was clear that the National Organization for Civilization Coordination categorized buildings according to their steadfastness and continuity into categories. In addition, from the assembled literature, it was clear that many researches are involved in investigating the impact of adding nano-CaCO<sub>3</sub> and Kaoline. For example, S.I. Zaki, et al 2018 compared the impact of Nano calcium carbonate and Nano kaoline properties. Their results confirmed that the proportions of calcium carbonate nanoparticles of CaCO<sub>3</sub> and nano kaoline that reduced concrete flowability and improved compressive strength of concrete were 1% and 7%, respectively. In addition, Mohamed, A. M. 2016 studied the effect of nano materials on flexural and compressive strength of concrete of Nano-Silica (NS), Nano-Clay (NC) and NS together with NC, his results flagged-out that nano particles improved the concrete mechanical properties. Furthermore, Kaszynska.2003 advocated that the application of Self-Consolidating Concrete “SCC” was efficient, her results confirmed the importance of superplasticizer, she designated that SCC was an efficient material for repairing concrete structures.

## EXPERIMENTAL STUDY

During the experimental study, materials were prepared; mixes were obtained; restored cubes were prepared and experimental investigations to their physical and mechanical properties were carried out.

## IMPLENTED MATERIALS

The implemented materials were sand, coarse aggregate and ordinary Portland cement (CEM I 52.5 N), while nano kaoline and nano calcium carbonate were used as partial replacement of cement. In addition, a chemical admixture was added. The description of the implemented material was as follows:

- **Cement:** The used cement was Ordinary Portland (OPC) , (CEM1 52.5 N) obtained from Elaskary Cement Factory with standard specifications (ESS 4756-1).
- **Fine Aggregate:** The employed fine aggregate was local natural siliceous sand in a regular spherical structure with a maximum grain size of 1.4 mm obtained from Giza Quarry with a specific gravity of 2.5. Its particle size distribution lies within the the classification of the Egyptian code (ECP 203-2018).
- **Coarse Aggregate:** The implemented dolomite aggregate was obtained from Attaka-suze quarry with one cm diameter, according to the Egyptian Code: (ECP 203-2018).

- **Chemical Admixture:** A-MasterGlenium (RMC 315) was implemented. It is a third generation superplasticiser based on modified polycarboxylic ether, compatible with all types of cement. It is a dark brown liquid with a density of  $1.06 \pm 0.02 \text{ g/cm}^3$  obtained from O-BASF Company in Egypt. Its properties are listed in table (1). In addition, B-ADDIBOND (65) was implemented. It was a versatile adhesive used for bonding fresh to old concrete.
- **Nano Powders:** The implemented nano powders were nano Calcium Carbonate and nano kaoline. They were produced by thermal activation by burning the raw material in a flat plate with a maximum layer thickness 4 cm at  $800 \text{ }^\circ\text{C}$  for 2 hours in an airtight oven in the Fire laboratory of Housing and Building Research Center (HBRC). The material was gradually cooled to air temperature ( $27 \text{ }^\circ\text{C}$ ) so as not to agglomerate. They were examined with a transmission electron microscope (i.e. JEOL –JEM – 2100), figure (1) in the National Research Centre to determine their particle size. Their sizes are listed in table (2). The implemented nanoparticles were as follows:
  1. Nano kaoline: The implemented nano kaoline is montmorillonite clay ( $\text{OH}_4 \text{ Si}_8 \text{ AL}_4 \text{ O}_{20}\text{n}$ ) obtained from Heliopolis for mining with grinding of 25 -100 microns. It is in crystalline state characterized by longer length relative to its thickness. Figure (2) presents its TEM micrograph after burning in HBRC.

**2. Nano Calcium Carbonate:** The implemented nanoCalcium carbonate (caco<sub>3</sub>) is obtained from Egyptian Carbonate company, with grinding 15 microns in crystalline state with a spherical shape. Figure (3) presents its TEM micrograph after burning.

**Table(1):** Technical Data and Physical properties of Master Glenium

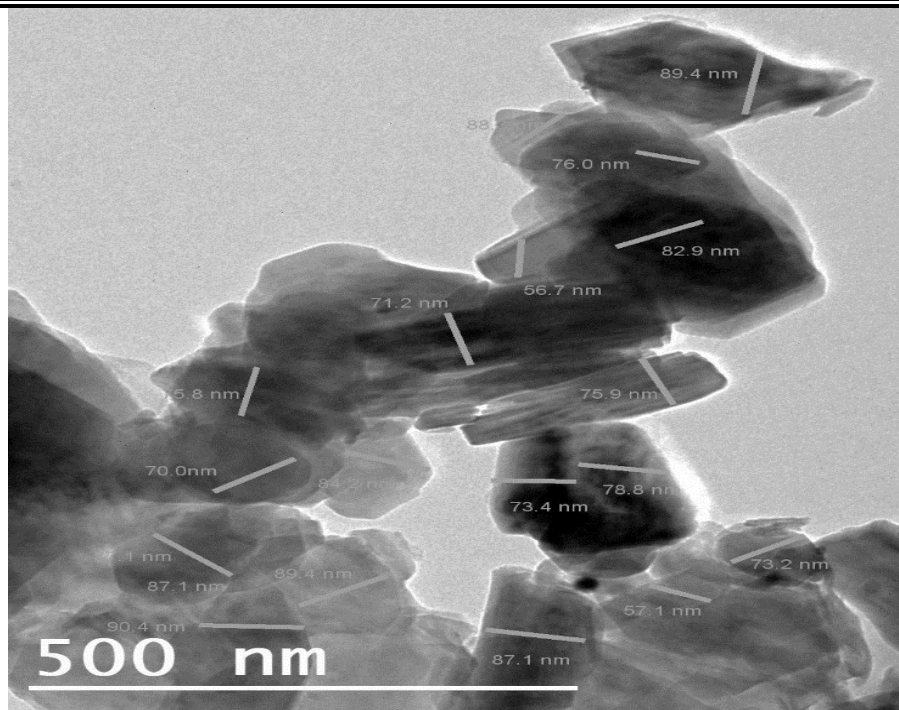
Form	Colour	Specific gravity	pH	Sulphate	Alkali content	Chloride ion
Viscous liquid	cream	1.075-1.085 at 25C0	5-8	Less than 1 gm/1tr	Less than 5 gm/1tr	Less than 0.1% w/v (nil)



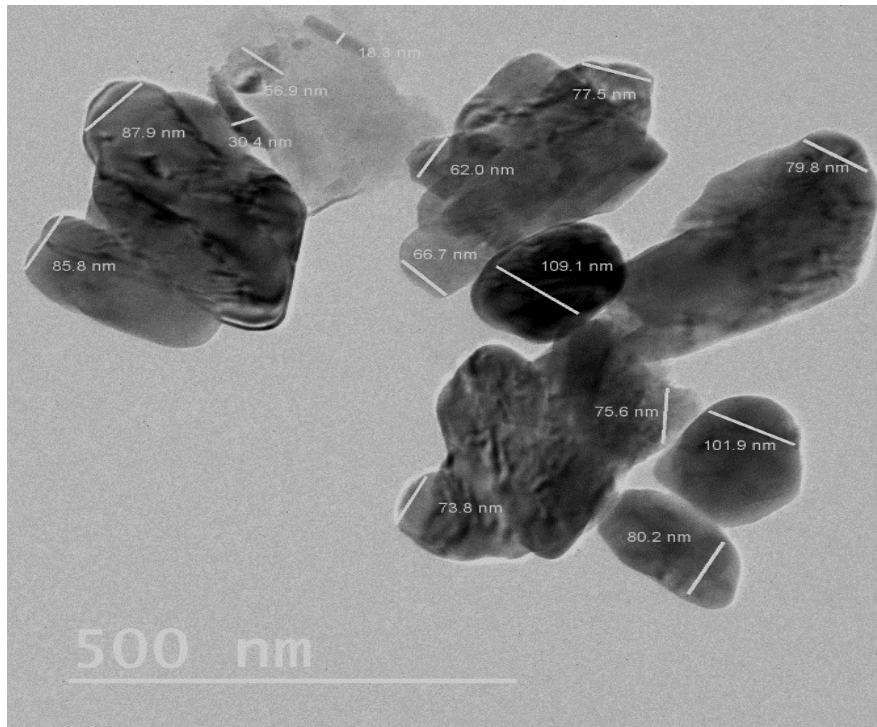
**Fig(1):** TEM JEOL –JEM – 2100

**Table (2):** Physical properties of nano particles

Nano Type	color	Mean Partical Size (nm)
Nano Calcium Carbonate	White	60
Nano kaoline	Light Cream	70



**Fig(2):** TEM micrograph for nano kaoline and mean particles size 70 nm



**Fig (3):** TEM micrograph for nano CaCo3 and mean particles size 60 nm

**a) MIXES PREPARATION:** During the experimental study, a reference mix “C0” (without nano materials) was prepared for comparison purposes.

In addition, 9 concrete mixes were prepared, according to ECP, NO.203, 2018. Their cement content was 450 kg/m<sup>3</sup>. Their W/C was 0.28. The implemented cement type was CEM I 52.5. The water temperature was ~ 25 °C. Nanomaterials (Nano clay, Nano Calcium Carbonate) were mixed with 3% Master Glenium 315RMC admixture by weight of cementitious materials. Concrete samples were prepared, mixed, casted, cured and tested in the Material Laboratory of HBRC.



**The mixes were as follows:**

- Three mixes were prepared by adding Nano-CaCo<sub>3</sub> to concrete at a percentages of 1, 2 and 3%, as a partial replacement of cement.
- Three mixes were prepared by adding NK to concrete at a percentages of 5, 6, and 7%, as a partial replacement of cement.
- Two hybrid mixes were obtained by adding 1% NCa + 5%NK and 0.5% NCa + 4.5% NK, as partial replacement of cement.

**b). EXPERIMENTAL PROGRAM:** An experimental program was designed, it was classified into two main parts, as follows:

- The first part inspected 9 concrete mixes to study the impact of using nanomaterials with different ratios (Nano Kaoline, Nano Calcium Carbonate) on the properties of fresh and hardened concrete in comparison to the reference mix “C0” (without nano materials), as listed in table (4).
- The second part tested an old 5 cm side concrete cube extracted from a 15 cm side test cube, where the additives ADDIBOND 65 was implemented to ensure adhesion between old and new concrete.

**c). INVESTIGATING CONCRETE PROPERTIES**

**Fresh mix and hardened concrete were investigated, as follows:**

- For the fresh concrete tests: Slump test was carried out to measure the consistency of concrete.
- For the hardened concrete tests: the following tests were carried out:

- Compressive Strength Test: The compressive strength is measured by testing concrete specimens in a compression-testing machine at 7,28 and 60 day.
- ✓ **Characterization by Scanning Electron Microscope (SEM):** Scanning electron microscope micrographs were carried out in HBRC to interpret the compressive strength results for control samples cubes and of concrete containing nanomaterials.

**Table (4):** concrete mix proportions.

MIX NO	Code of MIX	Mix proportion (Kg)					
		CEMENT	Fine aggrgate	Coars aggregate	Nano	Water	RMC315
C0	Control	450.0	720	1200	0	126	13.5
NK1	NK5%	414.0	720	1200	22.5	126	13.5
NK2	NK6%	409.5	720	1200	27.0	126	13.5
NK3	NK7%	405.0	720	1200	31.5	126	13.5
NCa1	NCoCa31%	432.0	720	1200	4.5	126	13.5
NCa2	NCoCa32%	427.5	720	1200	9.0	126	13.5
NCa3	NCoCa33%	423.0	720	1200	13.5	126	13.5
HN1	Hybrid 6%	409.5	720	1200	27.0	126	13.5
HN2	Hybrid 5%	414.0	720	1200	22.5	126	13.5

**Where :**

C0= Control Mix

NK1,2,3= includes 1,3,5% Nano kaoline by weight of cement, respectively.

NCa1,2,3=includes 5,6,7% NCoCa3 by weight of cement, respectively.

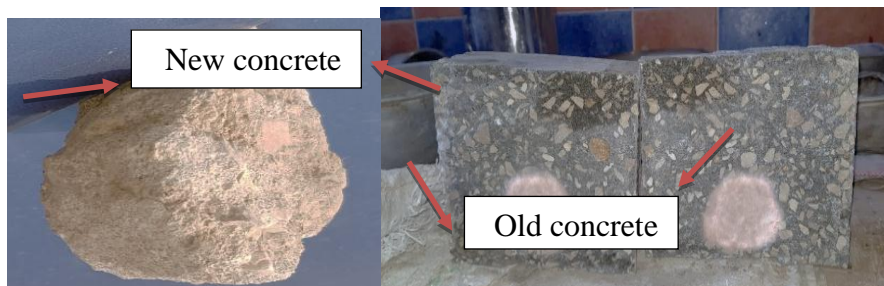
HN1=( 5% N kaoline +1% Nano calcium carbonate) (6% Hybrid) .

HN2=(4.5% N kaoline +0.5% Nano calcium carbonate) (5% Hybrid).

**d). INVESTIGATING RESTORED CONCRETE:** Experiments were carried out to evaluate the impact of restoring old concrete by nanoparticles concrete on its mechanical and physical properties, where the mixes partially replaced the structural elements needed to be restored in the Egyptian Syndicate.

Primarily, a full knowledge was perceived to the historical, architectural and Engineering aspects of the building. In addition, the state of the Egyptian Syndicate was monitored to identify the construction materials; designate the prevailing damage factor; distinguish the damage type and to identify the restoration method, Furthermore, they were documented.

the restoration steps proceeded by extracting old concrete cubes (15x15x15 cm) from cracked regions of the building. the extracted old cubes were partially replaced by the different nanoparticles concrete mixes (5x5x5 cm) that were bonded by additives (ADDIBOND), figure (4). Compression tests were carried out to the old concrete cubes restored by the nanoparticles concrete.



**Figure (4):** Old concrete bonded to nanoparticles concrete

## RESULTS ANALYSIS AND DISCUSSION

Throughout the analytical study, the obtained results were analyzed and presented on graphs and listed in figures for fresh (i.e. slump test), hardened concrete (i.e. compressive strength) and micro structure, as follows:

**a) FRESH CONCRETE SLUMP TEST RESULT ANALYSIS:** The slump experimental results were analyzed and scrutinized in order to signpost the impact of the different nanoparticles on fresh concrete:, from which the following was obtained:

- Table (5) lists the slump test results.
- Figure (5) presents the change in slump results for all mixes and the reference mix. The table and figure indicated that slump results were reduced by increasing the proportion of nano-kaoline and nano-CaCO<sub>3</sub>. As for the hybrid mix, the slump results increased at higher percentages, In addition, it was observed that all mixes slump results were less than the reference mix. Furthermore, the lowest slump values were obtained for mixes Nk3 and HN2, which indicated their low workability.

### **b) HARDENED CONCRETE COMPRESSIVE STRENGTH**

**RESULTS ANALYSIS:** Compressive experimental results were analyzed and scrutinized in order to designate the impact of the different nanoparticles on hardened concrete, from which the following was deduced:

- Table (6) lists the compressive test results. The table indicated the effect of nanomaterials at different replacement proportions of cement on the compressive strength after 7, 28 and 60 days, for NK, NCaCO<sub>3</sub> and hybrid

in comparison to reference mix. In addition, the table indicated that the highest compressive strength were achieved in NK1 (i.e. 674.5 kg/cm<sup>2</sup>), HN2 (i.e. 656 kg/cm<sup>2</sup>) and reference mix (i.e. 585.6 kg/cm<sup>2</sup>). Moreover, it was obvious that nanoparticles increased the concrete compressive strength by 14- 22 relative to the reference mix. Likewise, the table indicated the impact of **Nano-Kaoline** replacement ratios. Obvious was that the compressive strength was reduced at higher ratios of nano kaoline above 5%, where compressive strength were 516, 600, 675 kg/cm<sup>2</sup>, at 7, 28 and 60 days. Similarly, the table designated the impact of **Nano CaCO<sub>3</sub>** at replacement ratios of 1, 2 and 3%. Obvious was that 1% NCaCO<sub>3</sub> affected the early-age hardening process, which indicates that nano-CaCO<sub>3</sub> addition is a hardening accelerator. Correspondingly, the table flagged out the impact of **Hybrid Nano** replacement ratios on compressive strength. Aparent was that lowering the percentage than 5% increases the concrete compressive strength, where the suitable percentage was (4.5% kaoline +0.5% CaCO<sub>3</sub>), as it elevated the compressive strength by 12% above reference mix. Compressive strength increase is due to efficiency of nano particles in activating chemical reaction that consumes calcium hydroxide forming (C-S-H).

- Figure (6) presents the change in compressive results for mixes with nano kaoline and the reference mix. It presents the impact of **nano kaoline** on the concrete compressive strength, it was obvious that implementing

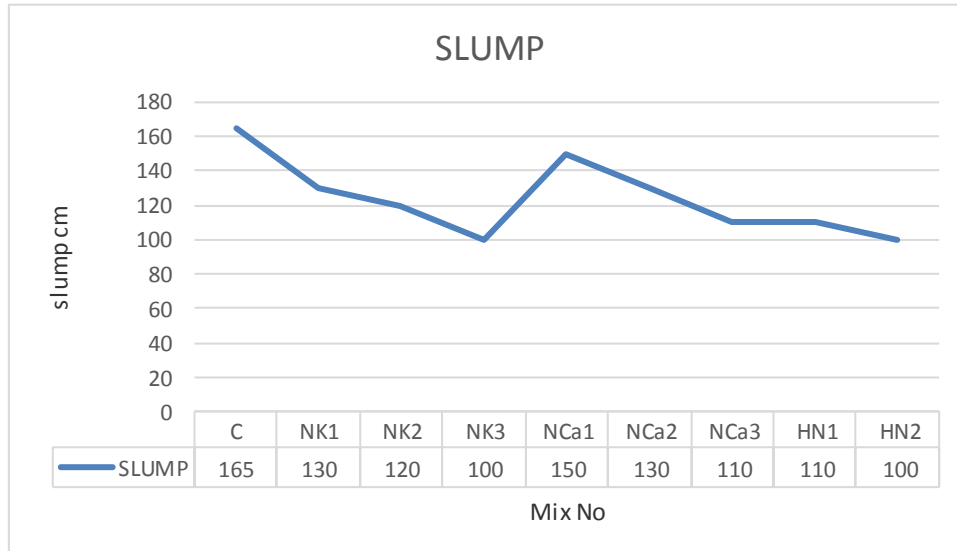
higher ratios than 5%, increased the compressive strength at 7, 28 and 60 days, (i.e. 516, 600, 675 kg/cm<sup>2</sup>). Furthermore, the figure indicated that the compressive strength results with NK 5% were higher by 15% above the reference mix. This is due to the nano particles presence that activates the chemical reaction that consumes calcium hydroxide to form additional (C-S-H), which is a gel material.

- Figure (7) presents the change in compressive results for mixes with nano CaCO<sub>3</sub> and the reference mix. The figure flagged out that the mix with 1% NCaCO<sub>3</sub> recorded the highest compressive strength (i.e. 487, 545, 605 kg/cm<sup>2</sup>) at 7, 28, and 60 days, respectively. This indicated that the compressive strength increased 6% above reference mix (i.e. adding 1% NCaCO<sub>3</sub>, achieved a compressive strength of 605 kg/cm<sup>2</sup>).
- Figure (8) presents the compressive results for mixes with hybrid nano and reference mix.

**Table (5):** Slump test results for all concrete mixes (after mixing)

MIX NO	C0	NK1	NK2	NK3	NCa1	NCa2	NCa3	HN1	HN2
Slump (mm)	165	130	120	100	150	130	110	110	100

**Where :** (C0= Control Mix - NK1,2,3= includes 1,3,5% Nano kaoline - NCa1,2,3=includes 5,6,7% NCaCo<sub>3</sub> - HN1= (6% Hybrid) - HN2 (5% Hybrid)).



**Figure(5):** slump test results for all mixes

**Where :**

C0= Control Mix

NK1,2,3= includes 1,3,5% Nano kaoline by weight of cement, respectively.

NCa1,2,3=includes 5,6,7% NCaCo3 by weight of cement, respectively.

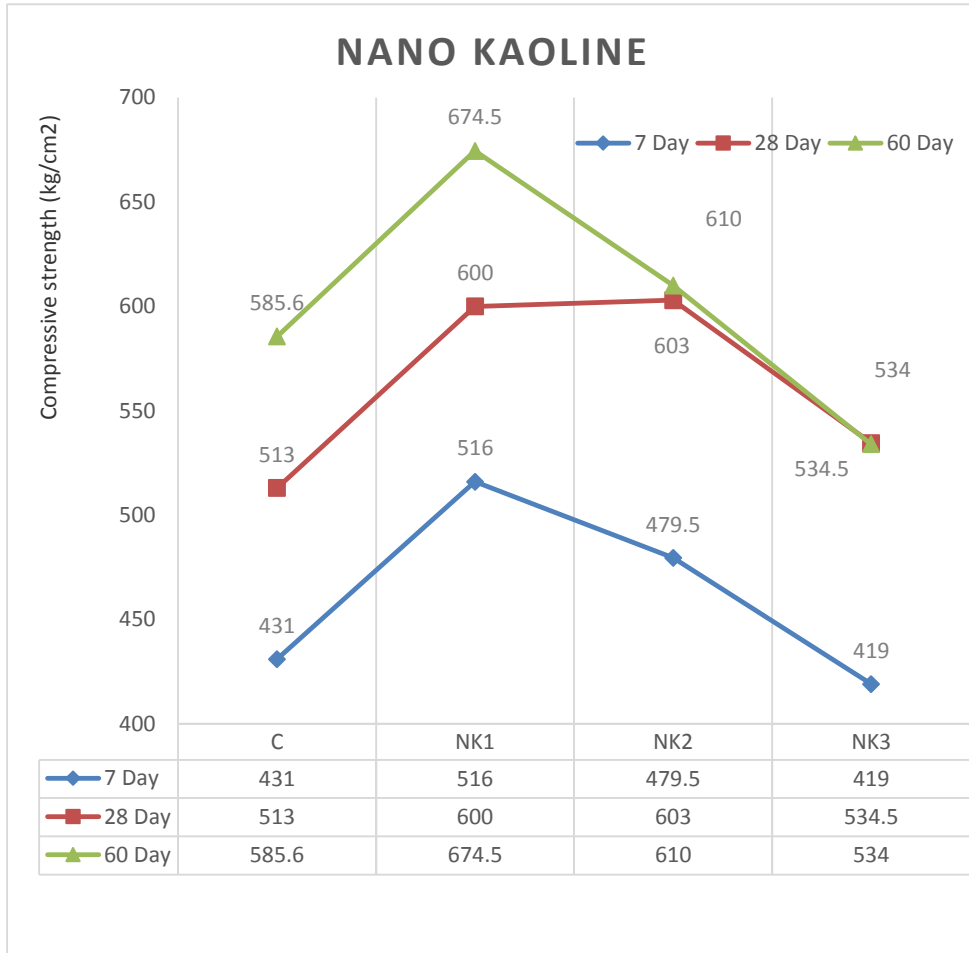
HN1=( 5% N kaoline +1% Nano calcium carbonate) (6% Hybrid) .

HN2=(4.5% N kaoline +0.5% Nano calcium carbonate) (5% Hybrid).

**Table (6):** compressive strength test results for all mixes

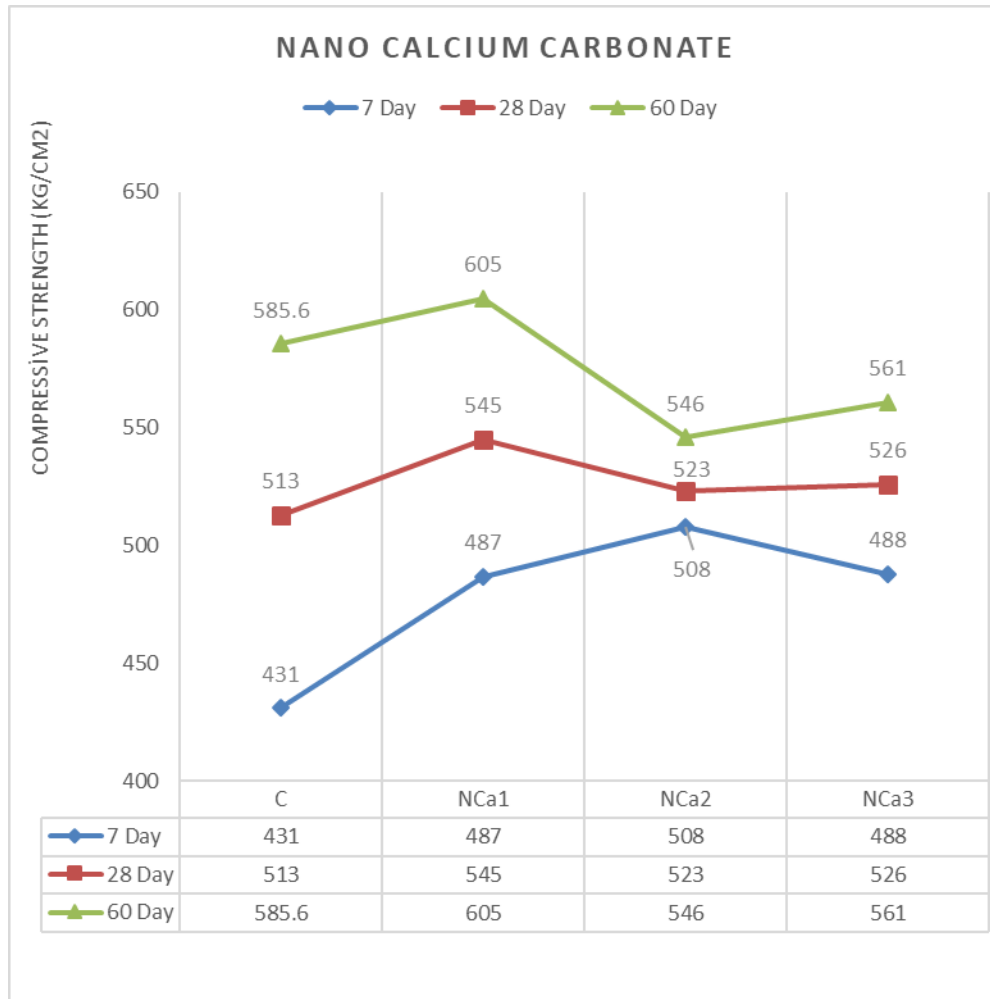
MIX	Time (Days)	Compressive strength (kg/cm <sup>2</sup> )	Details
C	7	431	control
	28	513	
	60	585.6	
NK1	7	516	5% Nano kaoline
	28	600	
	60	674.5	
NK2	7	479.5	6% Nano kaoline
	28	603	
	60	610	
NK3	7	419	7% Nano kaoline
	28	534.5	
	60	534	
NCa1	7	487	1% Nano CaCo <sub>3</sub>
	28	545	
	60	605	
NCa2	7	508	2% Nano CaCo <sub>3</sub>
	28	523	
	60	546	
NCa3	7	488	3% Nano CaCo <sub>3</sub>
	28	526	
	60	561	
HN1	7	431.5	5%NK +1% NCaCo <sub>3</sub>
	28	513	
	60	549	
HN2	7	604	4.5%NK + 0.5% NCaCo <sub>3</sub>
	28	634	
	60	656	





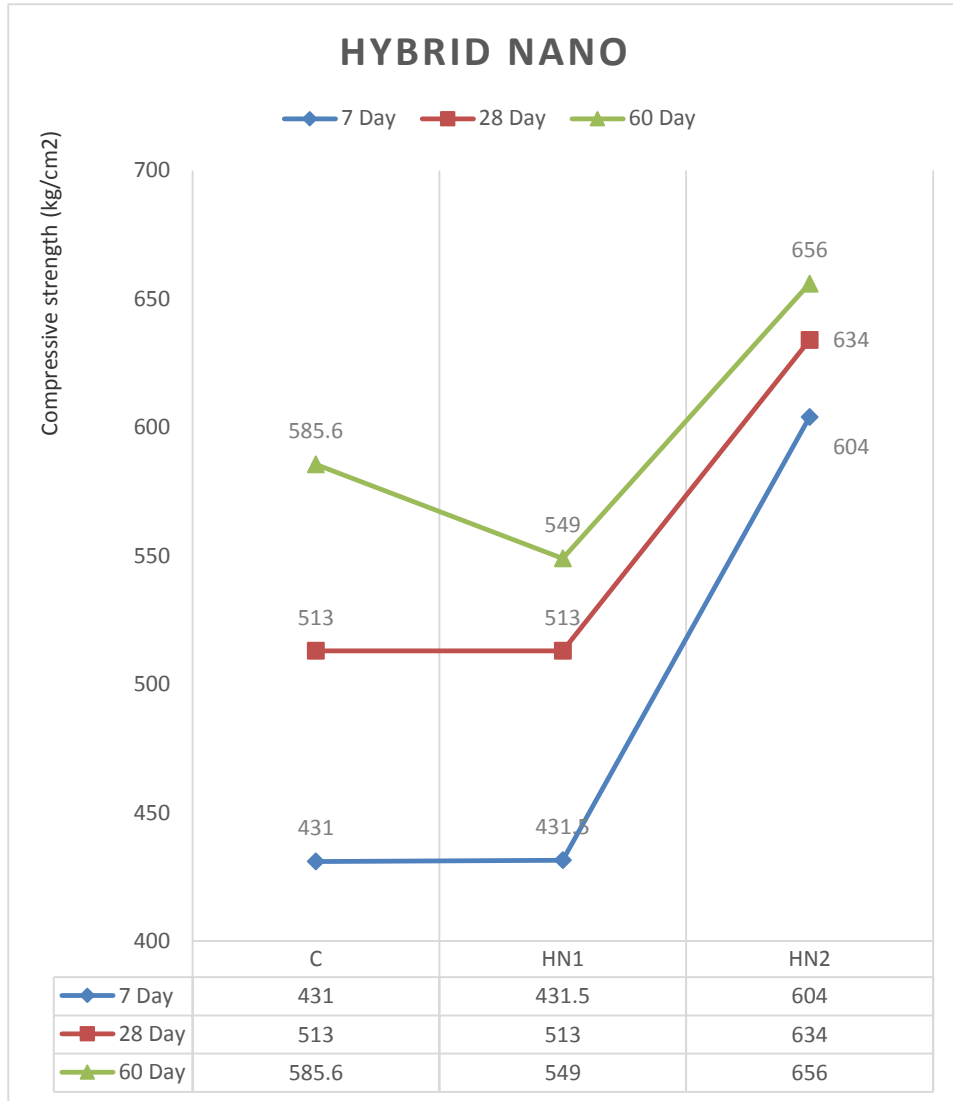
**Where :** (C0= Control Mix - NK1,2,3= includes 1,3,5% Nano kaoline).

**Figure (6):** Compressive strength for nano kaoline mixes compared to control mix.



**Where :** (C<sub>0</sub>= Control Mix -NCa1,2,3=includes 5,6,7% NCaCO<sub>3</sub>).

**Figure(7):** compressive strength for nano calcium carbonate (NCC) mixes compared to control mix.



**Where :** (C0= Control Mix - HN1= (6% Hybrid) - HN2 (5% Hybrid)).

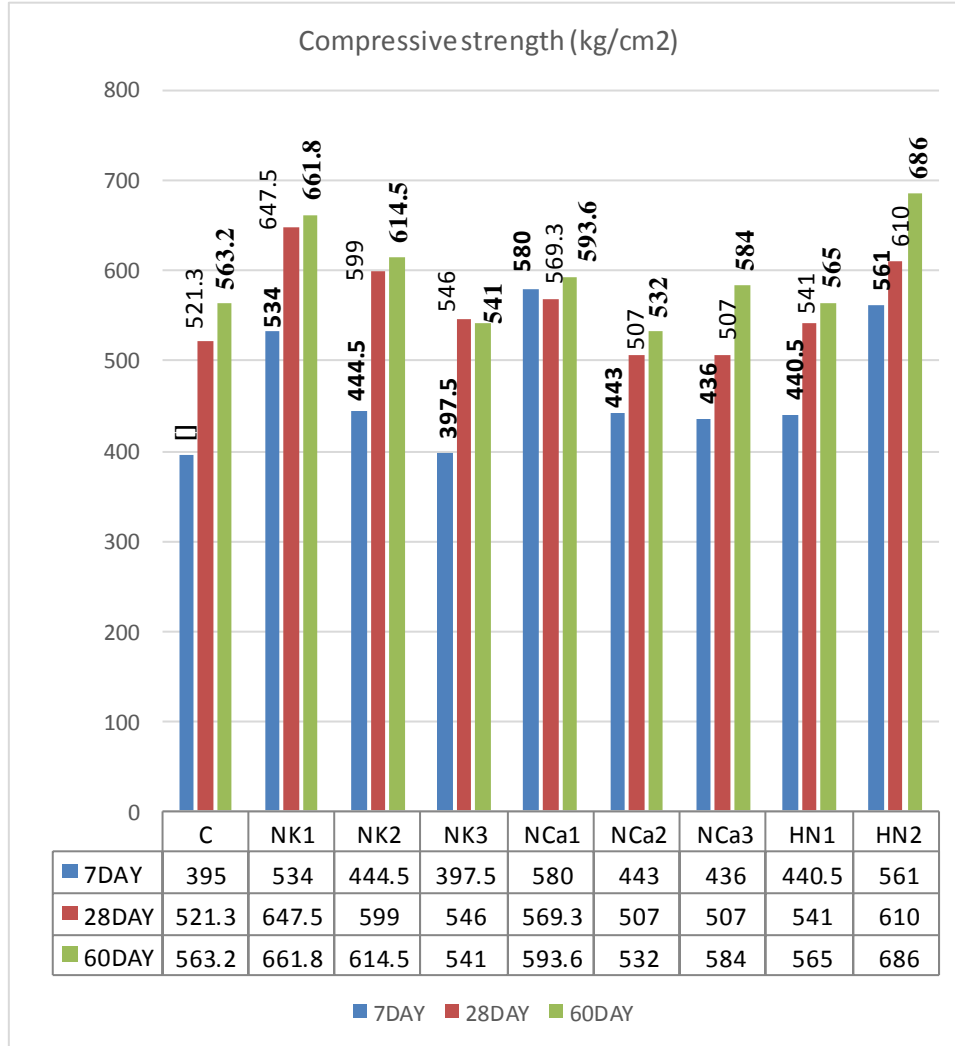
**Figure(8):** compressive strength for hybrid nano mixes compared to control mix.

**C.) CONCRETE RESTORATION RESULTS ANALYSIS:** Experimental results for examining the impact of employing nanoparticles in old concrete restoration were analyzed and scrutinized in order to designate the impact of the different nanoparticles on old concrete, where the following was produced:

- Table (7) lists the compression strength results, from which apparent was the following:
  - ✓ **Nano Koaline** ratio of 5%, provided the highest compressive strength of concrete. It increased the compressive strength of concrete by 11% compared to the reference mix.
  - ✓ **Nano CaCO<sub>3</sub>** ratio of 1% enhanced the compressive strength compared to the reference mix.
  - ✓ **Hybrid Nano** ratio of (4.5%Nkaoline+0.5%NCaCO<sub>3</sub>) achieved the highest compressive strength compared to the reference mix. It increased the compressive strength by 22% compared the reference mix.
- Figure (9) presents the average compressive strength of restored concrete, from which obvious was the following:
  - ✓ HN2 achieved the highest adhesion followed by NK1 and NCa1.
  - ✓ Hybrid concrete with 4.5% Nkaoline and 0.5% NCoCa3 achieved the highest compressive strength in the early-age.

**Table(7):** Compressive strength of restored concrete

MIX	Time (Days)	Compressive strength (kg/cm <sup>2</sup> )	Details
C	7	395.0	control
	28	521.3	
	60	563.2	
NK1	7	534.0	5% (Nano kaoline)
	28	647.5	
	60	661.8	
NK2	7	444.5	6% (Nano kaoline)
	28	599	
	60	614.5	
NK3	7	397.5	7% (Nano kaoline)
	28	546	
	60	541	
Nca1	7	580.0	1% ( Nano CaCo <sub>3</sub> )
	28	569.3	
	60	593.6	
Nca2	7	443	2% ( Nano CaCo <sub>3</sub> )
	28	507	
	60	532	
Nca3	7	436	3% ( Nano CaCo <sub>3</sub> )
	28	507	
	60	584	
HN1	7	440.5	5% Nkaoline +1% NCaCo <sub>3</sub>
	28	541	
	60	565	
HN2	7	561	4.5% Nkaoline+0.5% NCaCo <sub>3</sub>
	28	610	
	60	686	



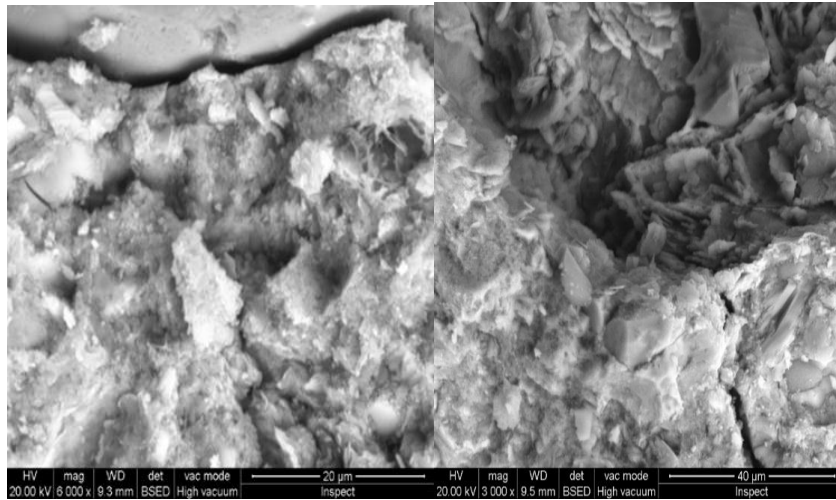
**Where:** (C<sub>0</sub>= Control Mix - NK1,2,3= includes 1,3,5% Nano kaoline - NCa1,2,3=includes 5,6,7% NCaCO<sub>3</sub> - HN1= (6% Hybrid) - HN2 (5% Hybrid)).

**Figure(9):** compressive strength for simulation of restoration concrete.

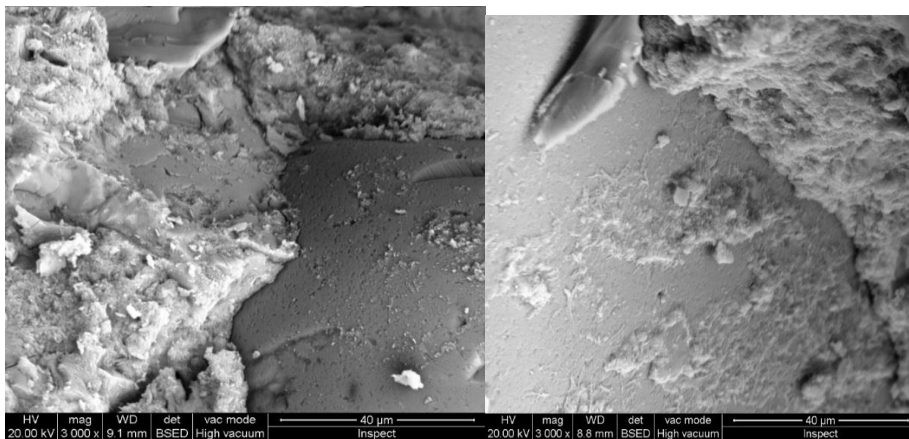
**f.) MICRO STRUCTURE RESULTS ANALYSIS:** Hardened concrete that provided the suitable results (i.e. NK1 and Nca1) micro structure study results were analyzed and scrutinized (It is to be noted that SEM samples were cut from crushed cubes with regular shape and flat surface), from which the following was produced:

- Figure (10) presents the SEM photograph of the reference mix without nano particles, where it was found that the inter filler zone was calcium-silicate-hydrate (C-S-H) gel that existed in the form of 'stand-alone' clusters. The photograph indicated the presence of voids and weakness bonds between the aggregate and the cement paste.
- Figure (11) presents the SEM photograph of concrete mix with 5% **Nano Kaoline**, where it was different from the reference mix. The photograph indicated the presence of crystals and the texture of hydrate products was denser and compact. This will enhance the mechanical properties and strengthen the structure. lot of crystal bonding in the structure. In addition, the photograph indicated the compact structure due to nano Kaoline nucleation effect and super filling effect that make the concrete dense with excellent mechanical properties.
- Figure (12) presents a SEM photograph for concrete mix with 1% nano  $\text{CaCO}_3$ , where no voids were present with good strength bonds between aggregate and cement paste. The photograph indicated dense and compact structure of concrete mix with enhanced mechanical properties due to

adding nano  $\text{CaCO}_3$ , as it activates of the hydration of cement and reacts with CH to form C-S-H gels.

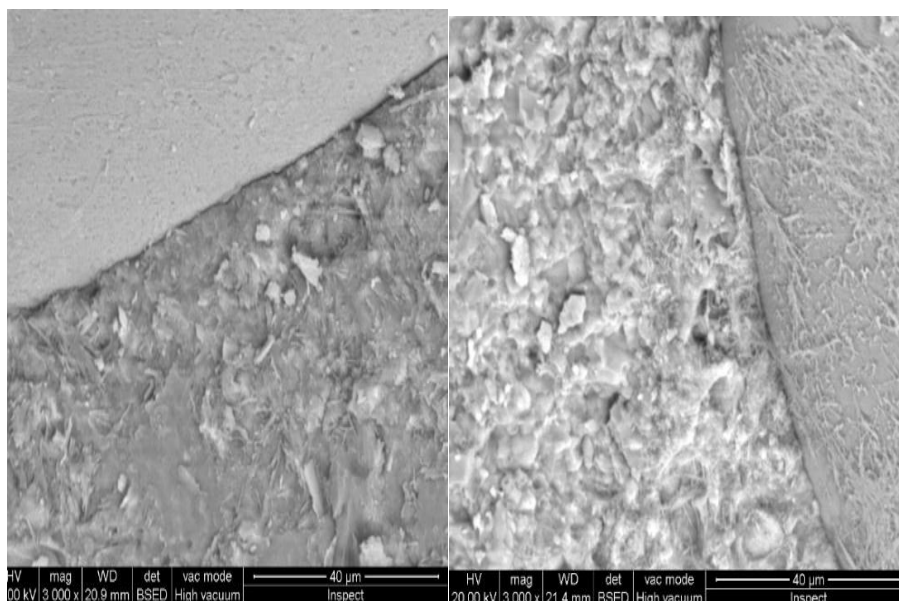


**Figure(10):** SEM micrographs of concrete without nanoparticles. C) N-0% (6000,3000 mag)



**Figure (11):** SEM micrographs of concrete with 5% nano kaoline NK) N-5% (6000,3000 mag)





**Figure (12):** SEM micrographs of concrete with 1% nano calcium carbonate (N-1%) (6000,3000 mag)

## CONCLUSIONS

**The following are the deduced conclusions from the present study:**

- The results indicated that adding nanoparticles reduced the concrete workability and its compressive strength, in comparison to the reference mix.
- The results designated that the suitable amount of the nano- $\text{CaCO}_3$  and NK nanoparticles were 1% and 5%, respectively.

- The hybrid nanoparticle proper amount was 0.5% for nano-CaCO<sub>3</sub> and 4.5% for NK, this proportion increased the hardening; achieved a better compressive strength so as adhesion to heritage building concrete and enhanced water permeability, in comparison to the reference mix.
- Restoration with nanomaterials enhanced the bond between old to nanoparticles concrete; compressive strength; impermeability and restoration quality.
- The SEM micrographs indicated that NK provided a dense concrete.
- The SEM indicated that adding NCaCO<sub>3</sub> up to 1% increases compressive strength.

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## دراسة تأثير استخدام تكنولوجيا النانو في ترميم المباني التراثية ( حالة دراسية: نقابة المهندسين )

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(١) طالب دراسات عليا بمعهد دراسات و البحوث البيئية، جامعة عين شمس (٢) أستاذ العمارة بمعهد الدراسات والبحوث البيئية، جامعة عين شمس (٣) أستاذ خواص المواد بمركز بحوث البناء والاسكان.

### المستخلص

نظرا لأهمية ترميم المباني التراثية في مصر، فتهدف الدراسة الى التحقق من تأثير استخدام تكنولوجيا النانو في ترميم المباني التراثية، على الخصائص الميكانيكية والفيزيائية لخرسانة الترميم، حيث أعتبر مبنى نقابة المهندسين، في شارع رمسيس، كحالة دراسية. وتشمل منهجية الدراسة تحقيقات نظرية ومعملية وتحليلية واستدلالية. وأثناء التحقق النظري، تم تجميع وبحث المؤلفات في مجال

ترميم المباني التراثية وعلم النانو. وأثناء التحقق المعملّي، تم إنتاج جسيمات نانوية من  $\text{CaCo}_3$  (نانو  $\text{CaCo}_3$  ونانو الكاولين). وبالإضافة إلى ذلك، تم خلطهم للحصول على جسيمات نانوية هجينة، بنسب مختلفة من نانو  $\text{CaCo}_3$  ونانو الكاولين. وتم إعداد خطة تحكم مرجعي للمقارنة. وعلاوة على ذلك، تم فحص تأثير الجسيمات النانوية، بنسب مختلفة، على خصائص الخرسانة الميكانيكية والفيزيائية. وبالإضافة إلى ذلك، تم التحقق من استخدام هذه الخلطات في عملية ترميم الخرسانة القديمة. ومن خلال التحقق بأجراء اختبارات مختلفة، وتم تحليل النتائج ومناقشتها. وخلال التحقق الاستدلالي، تم التوصل الى استنتاجات وتوصيات. وأشارت النتائج إلى أن إضافة جسيمات نانوية تحسن من قابلية التشكيل وقوة الخرسانة، بالمقارنة بالمزيج المرجعي. وعلاوة على ذلك، فإن النتائج أشارت الى الكمية المناسبة من نانو  $\text{CaCo}_3$  و NK وكانت 1% و 5%، على التوالي. ومن ناحية أخرى، فالكمية المناسبة للجسيمات النانوية الهجينة هي 0,5% ل Nano- $\text{CaCo}_3$  و 4,5% ل NK. حيث ارتفعت سرعة التصلب؛ وزادت قوة الخرسانة وقدرتها على الالتصاق بالخرسانة القديمة بالمباني التراثية وزادت عدم نفاذية الخرسانة، بالمقارنة للمزيج المرجعي. والابتكارية في هذه الدراسة، هو تحديد النسب المناسبة للجسيمات النانوية لضمان أداء الخرسانة في ترميم المباني التراثية.

**الكلمات الرئيسية:** المباني التراثية - الترميم - مواد النانو - النانو الهجين.