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Hybrid Effect of Metakaolin and Nano-Silica on Mechanical and Durability Parameters of Mortar

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Abstract: The incorporation of pozzolanic materials such as nano silica and metakaolin in cementitious materials has gained significant attention in recent years due to their potential to improve the mechanical and durability properties of cement-based composites. This thesis investigates the hybrid effect of nano silica and metakaolin on the mechanical and durability properties of cement mortar. The research work involved the preparation of cement mortar specimens with varying proportions of nano silica and metakaolin, which were then subjected to a series of mechanical and durability tests. The mechanical tests included compressive strength, while the durability tests included water absorption and elevated temperature test. The study showed that the addition of both nano silica and metakaolin to cement mortar resulted in a significant improvement in the mechanical properties of the mortar. Additionally, the hybrid effect of nano silica and metakaolin resulted in enhanced durability of the cement mortar, with a significant reduction in water absorption and improved temperature resistance. The findings of this study will have significant implications for the development of sustainable and durable cementitious materials. The use of pozzolanic materials such as nano silica and metakaolin can reduce the consumption of cement and the associated carbon footprint while also improving the durability and long-term performance of cement-based composites. Overall, this study suggests that the incorporation of nano silica and metakaolin can lead to significant improvements in the mechanical and durability properties of cement mortar, making it a promising material for use in various construction applications.
Keywords: microstructure, nanoparticles, mechanical properties, durability, metakaolin.

I. INTRODUCTION

As a finely ground material derived from lime oxides, cement has the ability to hold different minerals together in a compact form. Undoubtedly, Portland cement is one of the most important constituents of composite concrete. It has been reported that it is one of the most commonly used materials in developing countries. It is estimated that there are approximately 1.2 billion tonnes of cement produced globally in a year. However, when limestone is calcined to produce one tome of cement, enormous amounts of carbon dioxide (CO2), a greenhouse gas, are released.

A cement substitute or alternative material is required for sustainable building since the manufacture of cement results in excessive greenhouse gas emissions that cause the ozone layer to thin and other environmental concerns. The use of pozzolanic substitutes for cement, such as Silica Fume (SF), Fly Ash, Rice Husk Ash (RHA), Metakaolin, Nano Silica(NS), and Ground Granulated Blast Furnace Slag (GGBS), lowers CO2 emissions while also enhancing a number of the physical qualities of the concrete. To satisfy all the needs and expectations of the building industries, these materials have recently been adopted as a partial replacement for cement in the construction area. [34], cementitious materials to improve the power and reliability of cement mortar. Composite mate- rials with multi-scale internal structures hold an essential position in the assessment of new materials. Nanotechnology advancements have a significant effect on the concrete business. [22] Construction sector, intensive research is being conducted to enhance the performance of different building materials and to advance the devel-opment of durable and environmentally friendly concrete. Due to their pozzolanic properties, in addition to their pore-filling effect, nano-silica is the most commonly used substance in concrete and cement products to enhance its ability.

There is a great interest in replacing NPs in concrete structures to improve the chemical and physicomechanical properties of concrete. [4] Concrete and mortar, which are made from cement, are used a lot in building construction because they are strong, long-lasting, and easy to work with.

But these materials can still break down over time because of things like contact with the environment, chemical attacks, and mechanical stress. Researchers have looked into using admixtures like nano-silica and metakaolin to improve the strength and longevity of cement-based products.

A. *Supplementary Cementitious Materials (SCMs)*

Certain materials can effectively replace clinker, lowering the amount of CO2 emit- ted during the production of cement. A broad category of such materials that have been utilized to replace clinker in cement is defined by the name Supplementary cementitious Materials SCMs. Regarding their sources, they may be classified into two categories: materials that exist naturally or generated industrial waste byproducts. The right application of SCMs benefits concrete's qualities, such as long-term strength and endurance in challenging conditions. Additionally, there is yet another significant advantage to employing SCMs made from industrial waste. Supplementary Cementitious Materials (SCMs) are materials that are used in combination with Portland cement to enhance the performance of concrete. These materials are usually added in small amounts to the concrete mix, and they can improve various SCMs are commonly used in the construction industry as they offer several benefits, including reducing the environmental impact of concrete production. SCMs work by reacting with the calcium hydroxide in the concrete mix to form additional cementitious compounds. This reaction not only improves the strength and durability of the concrete but also reduces the amount of Portland cement needed, which results in lower carbon dioxide emissions and a more sustainable construction industry. Overall, the use of SCMs is becoming increasingly popular in the construction industry due to their ability to improve the performance of concrete while reducing its environmental impact.

B. *Nanosilica*

In the last few years, nano-silica (NS) has emerged as one of the most significant nanoparticles. Nanosilica, also known as silica dust or silica powder, is a substance that, such as, is distinguished by a high SiO2 proportion of more than 99%. [11].These particles were created by feeding worms rice husk, a biological waste product that contains 22% silicon dioxide. Finally, the precipitation approach can also pro- duce nScan. [28 The compressive, tensile, and flexural strengths of concrete have increased as a result of the addition of nano-silica to the mortar mix.

It typically requires admixtures during mix design since it sets early. After hydration, cement. with nano-silica in it can produce C-S-H gel nanocrystals. These nano-crystals fit into the cement Mortar's micropores, increasing the permeability and toughness of the material. [36] Nanosilica is a type of silica with particle sizes in the nanoscale range. It has unique properties that make it suitable for a wide range of applica- tions, including as a supplementary cementitious material (SCM) in mortar. As an SCM, nano-silica can improve the strength, durability, and other properties of concrete. It works by reacting with the calcium hydroxide in cement to form an additional calcium silicate hydrate (C-S-H) gel, which is the primary binding agent in concrete. This increases the overall density of the concrete, making it stronger and more durable. In addition to improving the strength and durability of concrete, nano-silica can also reduce the permeability of concrete, making it more resistant to water and chemical penetration. This can be especially useful in applications where the concrete will be exposed to harsh environments, such as in bridges or other in- frastructure. Overall, nano-silica is a promising SCM for concrete and mortar that has the potential to improve the performance and longevity of concrete structures. However, more research is needed to fully understand its properties and how it can be best used in concrete and mortar mixtures.

C. *Metakaolin*

It is known that metakaolin is a supplementary cementitious material that has poz-zolanic properties. A natural pozzolanic substance called Metakaolin is a natural pozzolanic substance that is essentially an anhydrous weakly crystallized aluminum silicate made through the calcination of the naturally occurring clay known as kaolin,which is predominantly made up of the mineral kaolinite (A12Si205 OH), as well as additional minerals like quartz, rutile, etc, depending on the deposit. It is common knowledge that adding such material to regular Portland cement OPC improves the performance of mortars and concrete. These advantages include enhanced sulfate.resistance, decreased permeability, reduced diffusion coefficients, and a higher level of long-term strength. [27] Metakaolin can be used as a supplementary cementitious material (SCM) in mortar to improve its properties and performance. When added.to mortar, metakaolin can act as a pozzolanic material, reacting with the calcium.hydroxide produced during the hydration of cement to form an additional calcium-silicate-hydrate (C-S-H) gel. This can improve the strength and durability of the mortar, as well as reduce its permeability.

In addition, metakaolin can also improve the workability and pump ability of mortar, making it easier to mix, transport, and to be placed in difficult or hard-to-reach areas. Overall, the use of metakaolin as an SCM in mortar can result in a material that is stronger, more durable, and more workable than traditional mortar mixes. This can be beneficial for a wide range of applications, including masonry, tile setting, and repairs.

D. Fly ash

Fly Ash, which is produced by coal combustion in electric power-producing facilities, is the most extensively used SCM in concrete. Fly ash is used in concrete under the classifications class C and Class F, which are detailed in ASTM C618. When used in mortaR, fly ash can improve the workability, strength, and durability of the mix. Overall, the use of fly ash as an SCM in mortar can be a cost- effective and sustainable option that can help improve the performance and environmental impact of the mix.

E. Slag (GGBS)

To create slag (GGBFS), molten slag from the iron-making process is quickly quenched. When mixed with water, the powdered form of this granular substance exhibits hydraulic capabilities. Slag cement is another name for GGBFS. An estimated 300. kg of GGBS may be produced for every tonne of pig iron, according to [29] GGBS is primarily constituted of lime, silica, and alumina, which is comparable to Port- land cement, despite the variance in chemical properties and physical structure Slag cement concrete frequently has greater compressive strengths, improved durability, and less permeability as compared to OPC concrete. To use slag as an SCM in mortar, it should be blended with the other dry ingredients before adding water. The amount of slag that can be used in the mix depends on its chemical composition, particle size distribution, and the desired properties of the mortar. Generally, slag can replace up to 50% of the cement by weight in mortar. Like fly ash, the use of slag as an SCM in mortar has environmental benefits as well. By using slag as a substitute for cement, the amount of cement required for the mix is reduced, which can help reduce carbon emissions associated with cement manufacturing. Additionally, using slag in construction can help divert this byproduct from landfills and turn it into a useful material. However, as with any SCM, the use of slag in mortar requires careful consideration of its properties and performance in the mix. The quality and. consistency of slag can vary depending on the source and manufacturing process, which can affect its performance in the mix. Overall, the use of slag as an SCM in mortar can be a cost-effective and sustainable option that can help improve the performance and environmental impact of the mix.

F. Silica fume

This byproduct material, also known as micro silica, is generated in an electric arc furnace by reducing high-purity quartz with coal and is utilized as a pozzolanic material. Additionally available in liquid form, silica fume is a very fine substance. When employing silica fume, the proper safety measures must be taken. These ma terials, which are described in ASTM C1240 (CSA A23.5), are frequently employed in situations that call for a high level of impermeability. When silica fume is used in concrete, the mixture will appear to become "sticky," and necessary changes may be needed. [25] Silica fume particles are much smaller than those of cement and other SCM materials, which allows them to fill in the spaces between cement particles more effectively. This filling effect can improve the packing density of the mortar, resulting in higher strength and reduced permeability. Silica fume also reacts with calcium hydroxide to form additional cementitious compounds, further enhancing the strength and durability of the mix. To use silica fume as an SCM in mortar, it should be blended with the other dry ingredients before adding water. The amount of silica fume that can be used in the mix depends on its chemical composition, particle size distribution, and the desired properties of the mortar. Generally, silica fume can replace up to 10% of the cement by weight in mortar. It is important to note that the use of silica fume as an SCM in mortar requires careful consideration of its properties and performance in the mix. Silica fume can have a significant effect on the rheology and setting time of the mix, and it can be difficult to work with due to its small particle size and high surface area. Therefore, it is important to test silica fume thoroughly before use and to optimize the mix design to achieve the desired properties.

II. EXPERIMENTAL INVESTIGATION

A. Materials

1) Metakaolin –As per IS-16354:2015 (METAKAOLIN FOR USE IN CEMENT, CEMENT MOR- TAR AND CONCRETE-SPECIFICATION), Metakaolin is Pozzolanic material obtained by calcination of pure or refined kaolinitic clay at a temperature between 650°C and 850°C to achieve complete dehydroxylation followed by grinding to a fineness of more than 900 m2/kg, when tested by BET method.
2) Nano-silica -Nano-silica is a very fine powder consisting of spherical particles or microspheres with a main diameter of 150 nm and a high specific surface area (15 to 25 m2/g). With this technique, it is possible to produce spherical nanoparticles with an 88% process efficiency. These particles were created by feeding worms rice husk, a biological waste product that contains 22% silicon dioxide. Nano-Silica had the benefits of a large specific surface area, powerful surface adsorption, large surface energy, high chemical purity, and excellent dispersion due to its tiny particle size.

3) Cement-Normal Portland cement of Grading 43 (OPC 43), developed by UltraTech Cement Ltd, was used in all mortar mixtures. The techniques outlined in the Bureau of Indian Standard norms are used to evaluate cement's physical properties, including its fineness, soundness, standard consistency, initial and final settling periods, strength under compression, and specific gravity.
4) Fineness of cement-The fineness of cement is an important feature that impacts the duration of the reaction of cement with water. Finer Cement has quicker action with water, though the ultimate strength is not much affected. Cement fineness also reduces bleeding. Shrinkage and cracking are more in finer cement due to an increase in strength gain rate. The fineness of cement is determined by using sieve analysis following IS-4031(P-1):1988. For using the sieve analysis method, take 100 gms of cement and sieve it on IS Sieve no. 9 (90 microns) for 15 minutes with the gentle motion of the wrists. To satisfy the fineness criterion, the retained residue shall not exceed 10% by weight of the sample.
5) Specific gravity of cement-Specific Gravity is defined as the ratio of a material's density to the density of reference material at a constant temperature. cement having 3.1 to 3.16 g/cc of specific gravity. According to this assertion, cement is 3.1-3.16 times heavier than water in the same amount. It also sinks in water because the specific gravity exceeds one. The specific gravity of cement is determined by using the Le chatlier apparatus. In this test, Le Chatelier's Flask is used 0 to 1ml with kerosene oil, and 1st reading is recorded after water bath at 270(+,-)20C. cement 64gms used flask after accurate weighing & recording it's weight. Roll the flask after putting the stopper so as to free the cement from any air bubbles, and take the level reading on the flask. Now, Sp gr. Weight of cement in gms/Displaced vol. in ml
6) Standard consistency of binder-The consistency of binder is defined as the amount of water added to cement to make a uniform paste that provides sufficient workability and proper strength. Adding less or an excess amount of water to the binder leads to a decrease in its strength.. The Vicat apparatus is commonly used to determine the consistency of cement- based materials. A standard cement paste is made using a certain water-cement ratio and a set quantity of cement in order to test the Vicat equipment to assess the consistency of the binder. The Vicat mould is then filled with cement paste, which is leveled with a spatula. The Vicat device is made up of a frame with a retractable rod and a plunger that is dropped into the cement paste's surface. At certain intervals, the plunger's penetration depth into the cement paste is measured. The plunger's time to achieve a certain penetration depth is used to calculate the cement paste's initial and final setting time frames. By examining the plunger's penetration depth over time, it is possible to gauge the consistency of the cement paste. The consistency is seen as occurring at a given penetration depth, often between 5-7mm. To guarantee that the concrete mix has the necessary workability and flowability, it is crucial to check the consistency of the binder during the building process. To achieve homogeneous strength and durability characteristics across the concrete construction, a constant binder consistency is crucial .As a result, it's critical to carefully monitor and modify the water-cement ratio as well as any other variables that may have an impact on the binder's consistency during mixing and application.
7) Fine aggregate (IS-Sand)- According to IS 650(1991) (Standard sand for testing cement), the standard sand must be silt-free and of quartz, light grey, or white form. The sand grains must be angular and close to being spherical in the structure; elongated and flattened particles must only be present in very little or no significant amounts. Ennore sand is commonly used in the preparation of cement mortar, particularly in construction applications. Its properties make it suitable for use as a fine aggregate in mortar mixes, which is typically composed of cement, sand, and water. The use of Ennore sand in cement mortar can provide several benefits, including improved workability, increased strength, and reduced shrinkage. The uniform particle size and well-graded nature of Ennore sand can help to achieve a consistent mix and reduce the likelihood of voids and weak spots in the mortar. However, it is important to note that the quality of Ennore sand used in cement mortar can have a significant impact on the overall quality and durability of the finished product. Sand that is contaminated with impurities or has a high clay content can compromise the strength and stability of the mortar. Therefore, it is important to source high-quality Ennore sand that has been properly processed and screened for use in cement mortar.
8) water-According to IS-456:2000, water, and cement interact chemically to cause the cement to form and harden. This process is known as cement hydration. Additionally, water lubricates the mixture and gives it the workability needed to place and compress it properly. Oil, acids, alkalis, salts, sugars, biological compounds, and any other substances that could harm concrete should not be present in the water used to make concrete. Generally, it should be of potable quality. Water should have a pH of between 6 and 8.5.

III. METHEDOLOGY

A. Prepration of Mortar Specimen

The preparation of mortar samples involves several steps that need to be followed carefully to ensure that the samples are of good quality and representative of the intended use. Here is a general procedure for preparing mortar samples:

1) *Materials:* The materials required for the mortar mix include cement, fine aggregate (sand), water, and any supplementary cementitious materials (such as nano silica and metakaolin).
2) *Mixing:* The materials should be mixed in a clean and dry container using a mechanical mixer. The mixing time should be sufficient to ensure that the materials are thoroughly blended, and a homogeneous mixture is obtained. The mixing time may vary depending on the type of mixer and the amount of material being mixed.
3) *Casting:* The mortar mixture should be cast into molds of the desired shape and size. The molds should be cleaned and coated with a release agent (such as vegetable oil or silicone spray) to facilitate easy removal of the specimens after curing.
4) *Compaction:* The cast mortar specimens should be compacted to remove any entrapped air bubbles and ensure that the mixture is evenly distributed in the mold. This can be achieved by using a vibrating table or a compacting rod.
5) *Curing:* The cast specimens should be covered with a plastic sheet or damp. cloth to prevent them from drying out and left to cure in a temperature- controlled environment for the recommended time period (usually 7 to 28 days). The curing temperature and time may vary depending on the type of cement. and the desired strength and durability properties. It is important to follow standard procedures and guidelines for preparing mortar specimens to ensure accurate and reliable test results.

B. Tests on Mortar

1) *Compressive Strength Test:* The most fundamental characteristic of hardened mortar is its compressive strength. Compressive strength testing was performed in accordance with Indian Standard Specifications using the steps outlined in IS-4031(P-6):1988. The compressive strength of concrete was evaluated at the age of 3 days, 7 days, and 28 days using standard cube specimens of size 70.6mm cube. A compression Testing Machine (CTM) of 2000 kN capacity was used to test the compressive strength of the mortar. To en- sure proper curing, mortar samples were demoulded 24 hours after casting and put in the curing tank. The specimen was positioned centrally between the bearing plates of CTM at each mentioned age, and the load was applied continuously and evenly at a set loading rate of 140 kg/cm2/min. The load was raised until the specimen broke, and the maximum load that each specimen could withstand was recorded. The compressive strength of mortar is calculated as per the formula. Compressive strength (maximum load / cross-sectional area) where the maximum load is the load recorded at the point of failure, and the cross-sectional area is the area of the specimen. The compressive strength results can be used to evaluate the strength and durability of the material and to compare the relative performance of different cement- based materials. High compressive strength values indicate that the material is more resistant to compressive loads and, therefore, more durable, while low values. indicate greater susceptibility to failure under compression. The results of the compressive strength measurement were computed using the average compressive strength of three cubes at 3 days, 7 days, and 28 days for each mortar mixture.
2) *Water Absorption:* Mortar cubes of size 70.6mm were cast for each mix in order to conduct the water absorption test and the rate of water absorption test. The water absorption test of mortar is performed as per ASTM C1585-13 [8].The samples were dried in an oven at 100C for 24 hr after curing. After oven drying, a polythene covering was placed over the mortar cubes' top and side surfaces. A flexible cord and water-resistant duct tape were used to secure the polythene covering in position. The cylinders' bottom surfaces were exposed to allow water to flow only in one way. They were positioned three millimeters above the water's surface, and water absorption was measured after (1 hr, 1 day, 3-day, and 7-day). and the age of water absorption was found. After water absorption, we performed a compressive strength test on the cubes.
3) *Elevated Temperature Test:* The cubes were first dried out at 100±5°C in an oven for 24 hours to get rid of the capillary water to lower the risk of spalling ; after that weight of all samples was measured, and then they were put inside a furnace to be exposed to heat whose interior temperature was raised to 200, 350, 500, and 650°C from the outside temperature. To achieve thermal equilibrium at the center of the specimens, the highest temperature was sustained for 3 hours at a rate of 3.3°C per minute from the room temperature of 22°C . The furnace was switched off after 3 hours, and the specimens were left inside until they cooled for another 3 hours. The specimens were then removed from the furnace. the specimens were permitted to cool gently in the air at room temperature for 24 hours, and then the weight of all specimens was taken and performed compressive strength on it.

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IV. RESULTS

The results of the numerous experimental studies are described and analyzed in this chapter. The results of the physical testing of the binder are provided in the first part. Physical tests for binders included determining the specific gravity, initial and final setting times, fineness, and compressive strength of cement mortar cubes. A different % of nano-silica and metakaolin is partially replaced with cement. Several experiments were carried out to determine how partially replacing nano-silica and metakaolin with cement affected the mortar's compressive strength, water absorption, and elevated temperature effect. These characteristics of various combinations are also compared and discussed.

A. *Properties of Raw Materials*

1) *Cement*

All concrete and mortar mixtures were made using Ordinary Portland Cement of Grade 43 (OPC 43), produced by UltraTech Cements Ltd. The cement was homo- geneous in color and free of any harsh lumps.

Table 1;Properties of Cement

Physical properties	Test Results	Specifications as per IS 8112:1989
Fineness (%agr retained on 90-micron sieve)	2	10(max)
Soundness (Le-Chatlier expansion in mm)	1mm	10mm(max)
Standard Consistency (%age)	32	-
Initial Setting Time	134 minutes	30 minutes(min)
Final Setting Time	503 minutes	600minutes(max)
Specific Gravity	3.10	-

2) *Consistency of Binder*

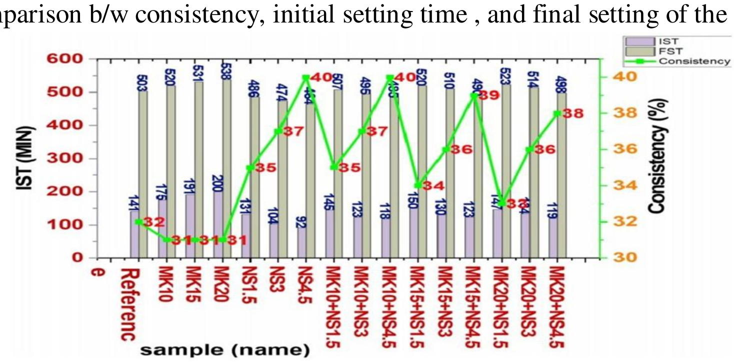
It has been shown that the characteristics of cement-based materials are significantly impacted by the mixture of nano-silica and metakaolin. The Vicat apparatus was used to examine the hybrid impact of these two materials on the consistency of the binder. The Vicat device measures the time needed for a plunger of size 10 mm to penetrate a cement paste to a certain depth in order to determine the consistency of cement-based products. While a lower penetration. depth denotes higher consistency, a larger penetration depth denotes lesser consistency. According to studies, adding metakaolin and nano-silica to cement may significantly affect the binder's consistency. In the initial and final setting times of the binder, the inclusion of nano-silica may have an impact on the consistency of the substance. On the other hand, the inclusion of metakaolin may enhance the binder's initial strength, which may potentially have an impact on consistency. the addition of metakaolin in cement does not have much effect on the consistency of the binder, whereas the nano-silica consistency of the binder increases, which means the amount of water required for hydration increases.

This is due to the very fine particles of the nano-silica.

a) Initial setting time of binder

b) Final setting time of binder

Comparison b/w consistency, initial setting time , and final setting of the binder



Comparison b/w consistency, initial setting time , and final setting of the binder

Sample	Consistency(%)	IST (min)	FST (min)
Ref	32	141	503
MK10	31	175	520
MK15	31	191	531
MK20	31	200	538
NS1.5	35	131	486
NS3	37	104	474
NS4.5	40	92	464
MK10+NS1.5	35	145	507
MK10+NS3	37	123	495
MK10+NS4.5	40	118	485
MK15+NS1.5	34	150	520
MK15+NS3	36	130	510
MK15+NS4.5	39	123	490
MK20+NS1.5	33	147	523
MK20+NS3	36	134	514
MK20+NS4.5	38	119	498

B. Mechanical Property of Mortar

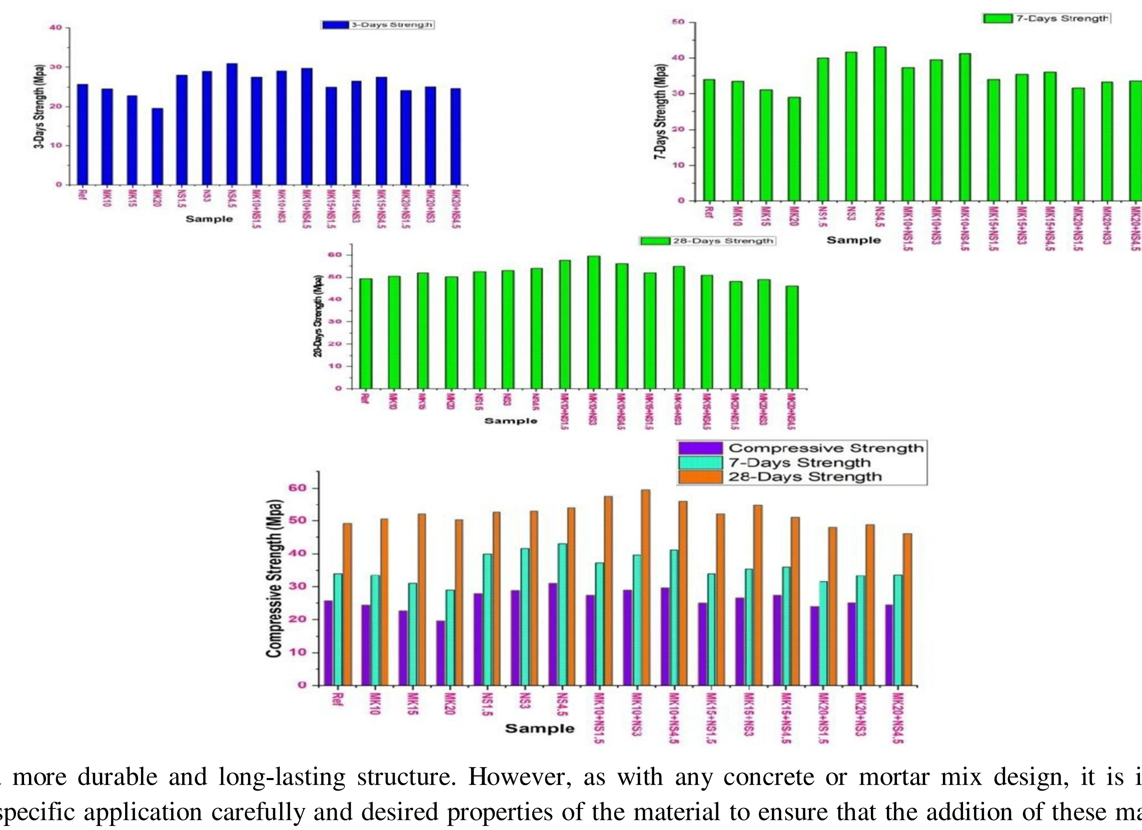
1) Compressive strength of Mortar

Nano silica and metakaolin are two commonly used pozzolanic materials that can be added to cement-based materials, such as mortar, to enhance their mechanical properties. Both materials have a high surface area and reactivity, which allows them to react with the calcium hydroxide produced during the hydration of cement, resulting in the formation of an additional calcium-silicate-hydrate (C-S-H) gel. The addition of nano-silica and metakaolin to mortar can improve the compressive strength of the material. Studies have shown that the addition of nano-silica can increase the compressive strength of mortar by up to 20%, depending on the dosage and particle size of the material. The improved strength is attributed to the densification of the mortar matrix due to the formation of additional C-S-H gel and the reduced porosity of the material. Similarly, the addition of metakaolin to mortar can also enhance its compressive strength. Metakaolin has a higher pozzolanic activity than silica fume and can react with calcium hydroxide to form additional C-S-H gel, leading to improved strength and durability of the material. Studies have shown that the addition of metakaolin can increase the compressive strength of mortar by up to 20%, depending on the dosage and quality of the material. Overall, the addition of nano-silica and metakaolin to mortar can have a significant impact on its compressive strength, making it a more suitable material for various construction applications. However, the dosage and quality of these materials must be carefully controlled to ensure optimal performance and to avoid any adverse effects on the properties of the mortar.The effects of various nano-silica and metakaolin content combinations on the compressive strength as assessed at ages 3, 7, and 28 days . It has been shown that adding simply nano-silica and metakaolin separately has less impact on the compressive strength of concrete. The compressive strength measured at 28 days increased by less than 7% when a dose of 1.5% NS was administered. On the other hand, at the age of 28 days, 10% MK produced a rise in compressive strength of roughly 4%. Because of this, it was predicted that using NS and MK together would improve mortar performance. Comparing all other mortar mixtures, a blend with a 3% NS and a 10% MK content had the maximum compressive strength across 28 days. At the age of 28 days, this mixture had 59.6 MPa of compressive strength, which was 21% greater than the appropriate control mix. The agglomeration of nanoparticles may be the cause of the compressive strength decrease with the addition of more than 3% percent NS. In theory, nanoparticles have bigger surfaces and greater surface energies, which leads them to clump together and create larger holes in concrete. [17].In contrast, the NS and MK combination would have a filler effect, increasing compressive strength, and the pozzolanic reaction would have occurred utilizing both components. The pore structure of concrete is refined and filled with fine metakaolin and nano-silica particles. Additionally, portland may be consumed by the pozzolanic reaction of nano-silica, which not only decreases the crystal size but also makes the hydration products more homogeneous. These facts have an impact on the interfacial transition zone (ITZ), which strengthens the connection between. the cement paste and the aggregates and improves the mechanical properties of concrete. [10]

2) Durability Properties of Mortar

Water Absorption of Mortar-Both nano silica and metakaolin are pozzolanic materials that react with calcium hydroxide in the cement to form additional calcium silicate hydrate (C-S-H) gel, which improves the microstructure of the cement paste and reduces its porosity. As a result, the water absorption of the cement mortar is reduced, leading to improved durability and resistance to weathering and other forms of deterioration. The exact degree of reduction in water absorption will depend on the specific mix design and the amount of nano silica and metakaolin added to the cement mortar. Generally, the addition of higher amounts of these materials is expected to result in a greater reduction in water absorption. However, it is important to carefully balance the mix design to ensure that the resulting cement mortar has the desired properties for its intended application. The reduction in water absorption can also be attributed to the improved packing density of the cementitious materials due to the addition of nano-silica and metakaolin. The pozzolanic reaction between these materials and cement produces a denser and more compact structure, which decreases the permeability of the cement paste and reduces its water absorption [19]. Additionally, the incorporation of nano silica and metakaolin can also result in the formation of a more stable calcium silicate hydrate (C-S-H) gel, which is a major contributor to the strength and durability of cementitious materials. The improved microstructure and stability of the C-S-H gel result in a more durable and water-resistant cement mortar. Overall, the addition of nano-silica and metakaolin to cement mortar can lead to significant improvements in the water absorption properties of the material,

Figure-Compressive Strenght at 3,7, and 28 days



resulting in a more durable and long-lasting structure. However, as with any concrete or mortar mix design, it is important to consider the specific application carefully and desired properties of the material to ensure that the addition of these materials does not negatively impact other critical properties such as compressive strength or workability [35] .The water absorption test provides an indirect measure of the durability of concrete; quicker and deeper water penetration will be a sign of insufficient durability. displays the outcomes of the water absorption test performed at a 7-day. The combination of nano-silica and metakaolin in the mortar samples produced a low water absorption, which is a sign of greater durability. In comparison to the control mix, the water absorption of the 15% MK concrete was reduced by 39%, while the water absorption of the 4.5% NS concrete was reduced by 40%. Similar to MK and NS alone, MK and NS together significantly decreased water absorption. In comparison to the water absorption attained in the control mix(Reference), the addition of 3% NS with a 10% replacement of MK has resulted in maximum (57%) reductions in water absorption. The decrease of water absorption in concrete was found to be more effective with the inclusion of nano silica combined. with 10% metakaolin, according to the results.

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3) Compressive Strength after Water Absorption

The combination of metakaolin and nano-silica can improve the compressive strength of mortar after water absorption compared to using either material alone. This is because the use of metakaolin and nano-silica can reduce the amount of capillary porosity in the mortar, which can improve its resistance to water absorption and subsequent damage due to freezing and thawing cycles. The addition of metakaolin and nano-silica can improve the microstructure of mortar after water absorption, as evidenced by the formation of denser and more uniform microstructures with fewer voids and cracks. This contributes to the improved compressive strength of the material after water absorption, as shown in the above table Overall, the hybrid effect of metakaolin and nano-silica on the compressive strength of mortar after water absorption can provide significant benefits for improving the durability and resistance of the material to moisture-induced damage. Due addition of 15% MK and 3% NS compressive strength. after water absorption increase by 15.5%. However, the specific results and optimal dosage of these materials can depend on several factors, and careful testing and evaluation are necessary to optimize their use for specific applications.

4) Mortar at Elevated Temperature

The addition of nano-silica and metakaolin to cement mortar can have a positive effect on its performance at elevated temperatures. Nanosilica is a highly reactive pozzolanic material that can improve the strength and durability of cement-based materials. When added to cement mortar, nano-silica particles fill the gaps between cement grains, reducing the porosity of the material and improving its mechanical properties. At elevated temperatures, the presence of nano silica can enhance the material's resistance to thermal cracking and spalling. Metakaolin is also a pozzolanic material that can be used to improve the performance of cement-based materials. When added to cement mortar, metakaolin reacts with calcium hydroxide to form additional calcium-silicate-hydrate (C-S-H) gel, which enhances the material's strength and durability. Like nano-silica, metakaolin can improve the resistance of cement mortar to thermal cracking and spalling at elevated temperatures. Studies have shown that the addition of both nano-silica and metakaolin to cement mortar can result in improved compressive strength, flexural strength, and resistance to elevated temperatures. However, the optimal dosage of these materials may vary depending on the specific application and conditions. It is important to conduct careful testing and evaluation of the effects of nano-silica and metakaolin on cement mortar under elevated temperature conditions to determine the most effective and efficient dosage levels for a particular application.Overall, the addition of nano-silica and metakaolin to cement mortar can provide a range of benefits, including improved mechanical properties, resistance to elevated temperatures, and durability in harsh environments. However, careful testing and evaluation are necessary to optimize their use for specific applications. In the indirect fire test, as temperatures increase, the compressive strength of mortar cubes initially increases up to 200 deg * C as shown in Fig. 16 and has no effect on the color of mortar cubes, further increase in temperature results decrease in compressive strength of 12.5% for Reference, 10% for MK15, 8% for NS3, and 7% for MK10+NS3 and has no effect on the color of mortar cubes. Similarly, at a temperature of 500 deg * C compressive strength of mortar cubes decreases, and the color of mortar cubes also changes. and At 650 deg * C mortar cubes start breaking, and six mortar cubes (MK10, MK15,MK20, MK15+1.5,MK20+NS3, MK20+NS4.5) breaks.

Strength at Different Temperature

SAMPLE	28-Days Strength	CS at 200°C (Mpa)	CS at 350°C (Mpa)	CS at 500°C (Mpa)	CS at 650°C (Mpa)
Ref	49.2	5.1	43	28	18
MK10	50.5	52.2	45.5	33.5	0
MK15	52	52.8	47	36	0
MK20	50.3	51.7	45.9	30.6	0
NS1.5	52.5	53.8	48	35.8	24.5
NS3	53	54	49.2	38.9	26.6
NS4.5	54	55.8	50.3	37.2	27.5
MK10+NS1.5	57.5	59	53	39.2	28.7
MK10+NS3	59.6	60.8	55.2	45	31.5
MK10+NS4.5	56	57.8	52.4	40	29.9
MK15+NS1.5	52	53.7	49	37.5	0
MK15+NS3	54.8	56	50.2	40.4	29.5
MK15+NS4.5	51	54.2	49.5	37	28
MK20+NS1.5	48	49.5	45	33	27.8
MK20+NS3	48.8	50	44.2	31.9	0
MK20+NS4.5	46	48.8	42	27.4	0

V. CONCLUSION

A. *Effect of Metakaolin and Nano-silica on Compressive Strength*

At an early age (3 and 7 days) strength gain of nano-silica blended mortar is higher, and metakaolin blended mortar is lower compared to normal cement mortar.Compressive Strength gain of cement mortar is maximum when combining the use of Nano-silica and metakaolin.

- The effective mix for the Compressive Strength of Mortar is MK10+NS3.
- At mix MK10+NS3, Compressive Strength increases by 21% compared to nor- mal cement mortar.

In conclusion, The combined use of metakaolin and nano-silica in cementitious materials has been shown to have a significant impact on the compressive strength. of mortar. Both metakaolin and nano-silica can contribute to the formation of additional C-S-H gel, which leads to an improvement in the strength of Mortar. The degree of improvement in compressive strength can vary depending on the proportion of metakaolin and nano-silica used, the curing conditions, and the type and source of cement.

B. *Effect of Metakaolin and Nano-silica on Water Absorption*

- When we added metakaolin to cement mortar, water absorption decreased and is minimum (1.24%) at mix MK15.When we added Nano-silica to cement mortar, water absorption decreased as we increased the amount of nano-silica.
- Water Absorption of cement mortar is minimum when combining the use of Nano-silica and metakaolin.
- The effective mix for the Compressive Strength of Mortar is MK10+NS3.At mix MK10+NS3, Water absorption decreases by 57% compared to normal cement mortar.

In conclusion, The use of metakaolin and nano silica in cementitious materials has been found to have a positive impact on reducing water absorption. Metakaolin and nano-silica can help to fill the pores and voids in the cement matrix, reducing the permeability of the material and limiting the ingress of water. The optimal proportion of materials may vary depending on the specific application and desired properties of the material. However, it is clear that the use of these materials can help to improve the durability and long-term performance of cementitious materials by limiting the ingress of water and other harmful substances.

C. *Effect of Metakaolin and Nano-silica on Mortar at Elevated Temperature*

- As the temperature increases, the compressive strength of all mixes increases up to 200°C. This is due to the hydration of cement.
- At 350°C Compressive strength of all mix decreases, but no change in the color of mortar cubes. At 500°C Compressive strength of all mixes decreases, and changes in the color of mortar cubes can be seen.
- At 650°C mortar cubes start breaking and six mortar cubes (MK10, MK15, MK20, MK15+1.5 MK20+NS3,MK20+NS4.5) breaks. The effective mix for the Elevated temperature of Mortar is MK10+NS3.
- Maximum residual strength of mortar cube at 500°C is 75% compared to room temperature(at mix MK10+NS3) .

In conclusion, the addition of metakaolin and nano-silica to mortar can have a positive impact on its properties at elevated temperatures. These additives can enhance the mechanical and physical properties of the mortar, including its strength, durability, and thermal stability. However, it is important to carefully consider the dosage and combination of these additives to ensure optimal performance under specific conditions. Further research is also necessary to fully understand the effects of metakaolin and nano-silica on mortar at elevated temperatures and to develop guidelines for their use in different applications.

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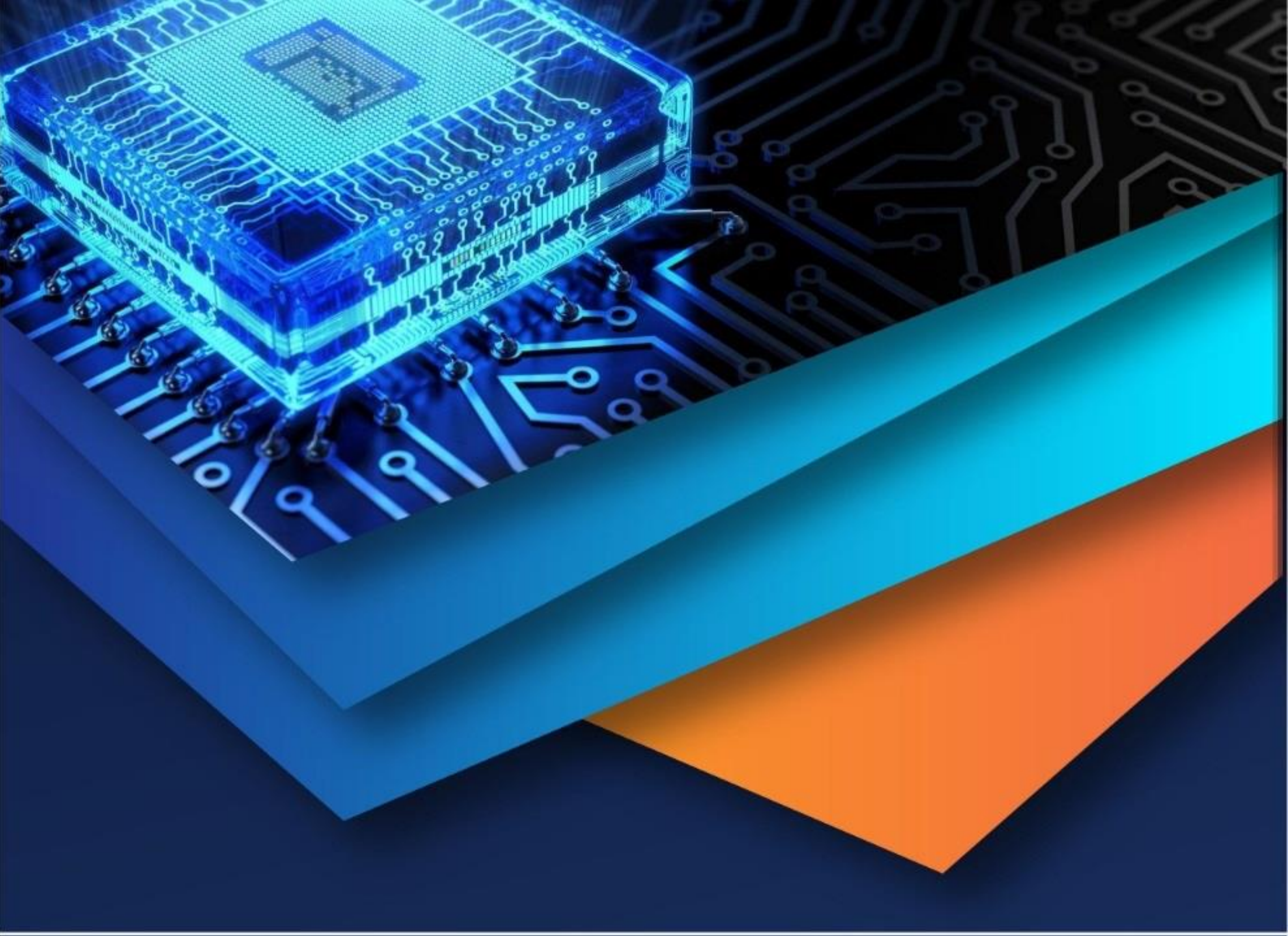

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