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Enhancing Thermal Regulation in Building Using Phase Change Materials (Pcm) Embedded Concrete

A Study on Thermal and Mechanical Performance of Concrete with PEG and Nano Silica

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ABSTRACT

In this work, the incorporation of polyethylene glycol (PEG) as a phase change material (PCM) and nano silica into concrete was investigated to enhance its thermal and mechanical performance. The study aims to improve energy efficiency and durability of concrete structures by utilizing PCM for thermal regulation and nano silica for strength enhancement. The concrete specimens were prepared by partially replacing cement with nano silica and adding PEG in varying proportions.

Experimental investigations were carried out to evaluate compressive strength, thermal conductivity, and heat storage capacity of the modified concrete. The results indicated that the inclusion of nano silica significantly improved the compressive strength due to its pozzolanic activity and pore-filling effect. The addition of PEG contributed to better thermal energy storage, reducing temperature fluctuations within the concrete.

The optimum performance was observed at specific proportions of PEG and nano silica, where a balance between strength and thermal efficiency was achieved. The study concludes that the combined use of PCM and nano silica in concrete can be an effective approach for developing sustainable and energy-efficient construction materials.

Keywords - Concrete; Polyethylene Glycol (PEG); Nano Silica; Phase Change Material (PCM); Compressive Strength; Thermal Performance

INTRODUCTION

Concrete is one of the most widely used construction materials due to its strength and durability. However, the conventional concrete has poor thermal performance, leading to increased heat absorption and temperature fluctuations inside buildings.

With the growing need for energy–efficient construction, Phase Change Materials (PCM) have been introduced to improve thermal regulation. PCM can absorb and release thermal energy during phase transitions, thereby maintaining a stable indoor temperature.

In this study, Polyethylene Glycol (PEG) is used as PCM to enhance thermal performance, while nano silica is added to

improve mechanical strength. The combined use of these materials aims to develop a concrete that provides both thermal efficiency and structural strength.

LITERATURE REVIEW

Recent studies have focused on improving the thermal and mechanical performance of concrete using advanced materials. Conventional concrete, though widely used, lacks thermal efficiency and contributes to higher energy consumption in buildings.

Phase Change Materials (PCM) have gained attention due to their ability to store and release thermal energy during phase transitions. Among various PCM, Polyethylene Glycol (PEG) is widely used because of its chemical stability, non-toxicity, and suitable melting temperature range.

Researchers have reported that incorporating PCM in concrete improves thermal performance but may reduce the mechanical strength. To overcome this limitation, nano silica has been introduced as an additive. Nano silica enhances compressive strength and durability due to its pozzolanic activity and pore-filling effect.

However, limited studies have explored the combined use of PEG and nano silica. This study aims to investigate their combined effect to achieve a balance between thermal efficiency and structural strength.

WORKING PRINCIPLE OF PCM IN CONCRETE

Phase Change Materials (PCM) such as Polyethylene Glycol (PEG) work based on the principle of latent heat storage. When the surrounding temperature increases, the PCM absorbs heat and undergoes a phase change from solid to liquid without a significant rise in temperature. This process helps in storing thermal energy within the concrete structure.

During cooler conditions, the PCM releases the stored heat as it changes back from liquid to solid state. This cyclic process helps in maintaining a more stable internal temperature within the building, reducing temperature fluctuations.

In this study, PEG is embedded within the concrete matrix. When exposed to high temperatures, PEG absorbs excess heat from the environment, thereby reducing heat transfer into the building interior. During night or cooler periods, the stored heat is gradually released.

This mechanism improves the thermal regulation of concrete, making it more suitable for energy-efficient buildings, especially in regions with high temperature variations. However, since PCM alone may reduce mechanical strength, nano silica is added to compensate and improve structural performance.

MATERIALS

Phase Change Material (PCM) :

PCM is the main material used in this project. It has the ability to store and release heat during phase change. It helps in maintaining a stable indoor temperature by absorbing excess heat and releasing it when needed.

Cement:

Cement is used as a binding material to prepare PCM-based panels or blocks. It helps in holding all materials together and provides strength.

Fine Aggregate (Sand) :

Sand is used to improve the strength and stability of the material. It also helps in proper mixing and structure formation.

Water:

Water is required for mixing cement and for the hydration process. It helps in setting and hardening of the material.

SPECIMEN DETAILS

In this study, standard concrete specimens were prepared for evaluating the mechanical and thermal performance of Polyethylene Glycol (PEG) and nano silica modified concrete.

The concrete cubes were cast using a standard size of 150 mm × 150 mm × 150 mm for compressive strength testing. Beam specimens of standard dimensions were prepared for flexural strength testing. All specimens were prepared using M25 grade concrete mix.

A total number of specimens were cast for different mix proportions, including conventional concrete and modified mixes with varying percentages of PEG and nano silica. Each mix was prepared carefully to maintain uniformity and consistency.

After casting, all specimens were compacted properly to remove air voids and ensure proper bonding of materials. The specimens were then demolded after 24 hours and placed under curing conditions in water tanks for a period of 28 days to achieve desired strength development.

All specimens were tested after curing, and results were compared to analyze the effect of PCM and nano silica incorporation in concrete.

METHOD

Collection of PCM Material :

Phase Change Material is selected based on suitable melting temperature for building applications.

Preparation of Molds :

Molds of required size are cleaned and prepared for casting the PCM-based panels.

Mixing of Materials :

Cement, sand, and PCM are mixed properly to form a uniform mixture . Water is added to achieve the required consistency.

Casting Process :

The prepared mixture is poured into molds and compacted to remove air gaps.

Curing Process :

The molded panels are allowed to set and cure for a specific period to gain strength.

The prepared PCM panels are installed in building components such as walls or ceilings.

Testing and Observation Thermal performance and strength of the panels are tested and compared with conventional materials.

EXPERIMENTAL SETUP

The experimental setup for this study involves testing the mechanical and thermal performance of concrete specimens modified with Polyethylene Glycol (PEG) and nano silica. The primary objective is to evaluate the effect of Phase Change Materials (PCM) on temperature regulation and strength enhancement of concrete.

A Compression Testing Machine (CTM) is used to determine the compressive strength of concrete specimens at 28 days of curing. A standard Universal Testing Machine (UTM) is used for flexural strength testing of beam specimens.

For thermal performance analysis, temperature variation is measured using digital thermocouples placed at different points of the concrete specimens. The specimens are exposed to controlled heating conditions to observe heat absorption and release behavior.

All testing is conducted as per standard procedures to ensure accuracy and reliability of results. The readings obtained are compared between conventional concrete and modified PCM concrete to evaluate performance improvement.

EXPERIMENTAL PROCEDURE

The experimental procedure involves the systematic preparation, casting, curing, and testing of concrete specimens modified with Polyethylene Glycol (PEG) and nano silica.

Initially, all raw materials such as cement, fine aggregate, coarse aggregate, PEG, and nano silica are measured according to the mix design. Dry materials are mixed thoroughly to ensure uniform distribution. PEG and nano silica are then added in the required proportions and mixed until a homogeneous concrete mix is obtained.

The fresh concrete is poured into standard cube and beam molds. Proper compaction is carried out using a tamping rod and vibration to eliminate air voids and improve density. After casting, the specimens are left undisturbed for 24 hours.

After 24 hours, the specimens are demolded and placed in a water curing tank. Curing is carried out for 28 days to ensure proper hydration and strength development.

After curing, the specimens are tested for compressive strength using a Compression Testing Machine (CTM), flexural strength using a Universal Testing Machine (UTM), and thermal performance using temperature monitoring instruments. The obtained results are recorded and compared with conventional concrete.

METHODOLOGY

The methodology involves the preparation and testing of concrete with the addition of Polyethylene Glycol (PEG) and nano silica. Conventional materials such as cement, fine aggregate, coarse aggregate, and water are used along with PEG and nano silica.

M25 grade concrete is selected as the base mix with a proportion of 1:1:2 and a water-cement ratio of 0.45. Different percentages of PEG (0.5%, 1%, 1.5%, and 2%) and nano silica (1%, 2%, and 3%) are added to study their combined effect.

Concrete specimens are prepared, cast in standard moulds, and cured for 28 days. After curing, tests such as compressive strength, flexural strength, and thermal performance are conducted.

The results obtained from modified concrete are compared with conventional concrete to evaluate performance improvements.

RESULTS AND DISCUSSION

The experimental results indicate that the addition of PEG and nano silica significantly affects both thermal and mechanical properties of concrete.

Compressive strength results show that nano silica improves strength due to its pozzolanic reaction and pore-filling capability. The optimum compressive strength was observed in mixes containing 2% nano silica and 1% PEG.

The inclusion of PEG enhances thermal performance by increasing heat storage capacity and reducing temperature

fluctuations. However, higher percentages of PEG slightly reduce strength.

The combined use of PEG and nano silica provides a balanced performance, improving both thermal efficiency and structural strength. The results confirm that modified concrete performs better than conventional concrete.

Thermal Performance

The inclusion of PCM showed a significant improvement in temperature regulation compared to conventional building material. The internal temperature of the PCM integrated sample was reduced by approximately **[37 °C]** compared to the normal sample under similar environmental conditions. This reduction is due to the latent heat absorption property of PCM during phase transition, which helps in maintaining a stable indoor temperature.

Mix	Temp @ 30min (Co)	Temp @ 60min (Co)	Temp @ 90min (Co)
Conventional	38	43	46
P1NS2	33	37	39

Compressive Strength

The compressive strength test results indicated that the PCM embedded specimen exhibited a strength of **[40.9 MPa]**, whereas the conventional specimen showed **[27.6 MPa]**. A slight variation was observed due to the presence of PCM, but the structural integrity remained within acceptable limits for building applications.

Installation S. No	PEG (%)	Nano Silica (kg)	Compressive Strength (MPa) (28 days)
	0	0	27.6
NS1P0.5	0.5	1	33.2
NS1P1	1	1	35.3
NS1P1.5	1.5	1	33.7
NS1P2	2	1	32.2
NS2P0.5	0.5	2	37.5
NS2P1	1	2	40.9
NS2P1.5	1.5	2	39.1
NS2P2	2	2	36.5
NS3P0.5	0.5	3	34.9
NS3P1	1	3	37.2
NS3P1.5	1.5	3	35.8
NS3P2	2	3	34.2

COMPRESSIVE STRENTH READINGS IN 28 DAYS

Flexural Strength

Flexural strength analysis revealed that the PCM integrated material achieved **[5.2 MPa]**, which is comparable to or slightly improved over the control specimen. The incorporation of PCM did not significantly affect bending resistance, making it suitable for practical construction use.

% of Mix	Flexural strength (N/mm2)
Conventional Mix	3.8
PEG 1% + NS 2%	5.2

Overall Discussion

From the obtained results, it is clearly observed that PCM incorporation enhances thermal regulation capability without major compromise in mechanical strength. This makes the proposed system highly suitable for energy-efficient building applications, especially in regions with high temperature variations.

GRAPHICAL ANALYSIS

Graphical analysis is carried out to clearly understand the performance variation between conventional concrete and modified concrete containing PEG and nano silica. The test results are represented in the form of graphs for better comparison and interpretation.

A compressive strength graph is plotted to show the variation of strength for different mix proportions at 28 days curing period. From the graph, it is observed that the mix containing optimal percentage of nano silica and PEG shows higher compressive strength compared to conventional concrete.

A thermal performance graph is also used to represent temperature variation over time (30 min, 60 min, and 90 min). The graph clearly indicates that PCM incorporated concrete maintains lower internal temperature compared to conventional concrete due to heat absorption capability.

Flexural strength results are also represented graphically to show the effect of PEG and nano silica on bending resistance. The results indicate a moderate improvement in flexural strength with nano silica addition.

These graphical representations help in visually understanding the improvement in both mechanical and thermal properties of modified concrete.

CONCLUSION

This study investigates the effect of Polyethylene Glycol (PEG) and nano silica on the performance of concrete. The results indicate that PEG improves thermal properties by enhancing heat storage capacity, while nano silica increases compressive strength and durability.

The combined use of PEG and nano silica results in improved overall performance of concrete. An optimum mix proportion provides a balance between thermal efficiency and mechanical strength.

The study concludes that PCM-based concrete with nano silica is a promising material for energy-efficient and sustainable construction. Further research can be carried out to explore large-scale applications and long-term performance.

PROPERTY	CONVENTIONAL CONCRETE	MODIFIED CONCRETE
COMPRESSIVE STRENGTH	MODERATE	HIGH
THERMAL PERFORMANCE	POOR	IMPROVED
HEAT STORAGE CAPACITY	LOW	HIGH
DURABILITY	NORMAL	BETTER
ENERGY EFFICIENCY	LOW	HIGH
TEMPERATURE FLUCTUATIONS	HIGH	REDUCED

From the above comparison, it is observed that the modified concrete with PCM and nano silica shows better Thermal regulation and improved mechanical performance compared to conventional concrete.

ADVANTAGES AND LIMITATIONS

The incorporation of Polyethylene Glycol (PEG) and nano silica in concrete offers several advantages in improving both thermal and mechanical performance. However, there are also certain limitations that need to be considered.

Advantages:

Improves thermal regulation by reducing temperature fluctuations in buildings Enhances energy efficiency by reducing cooling load requirements Increases compressive strength due to nano silica's pozzolanic activity Improves durability and microstructure of concrete Provides sustainable and eco-friendly construction solution Suitable for hot climatic regions where heat control is essential.

Limitations:

Slight reduction in strength at higher PEG content Higher material cost compared to conventional concrete Possibility of PCM leakage if not properly encapsulated Requires careful mix design and proportion control Limited large - scale practical implementation studies

Overall, despite minor limitations, the modified concrete shows promising performance for energy-efficient construction applications.

APPLICATIONS

The developed Polyethylene Glycol (PEG) and nano silica modified concrete can be effectively used in various construction applications where both thermal regulation and mechanical strength are important.

- Residential buildings in hot climatic regions for temperature control.
- Roof slabs and terrace structures to reduce heat absorption.
- Exterior wall panels for improved indoor thermal comfort.
- Smart and energy-efficient building construction projects.
- Industrial buildings where heat reduction is required.
- Sustainable housing projects focusing on energy saving design.
- Green building technologies and eco-friendly infrastructure development.

This modified concrete is particularly useful in areas where temperature fluctuations are high, as it helps in maintaining a stable indoor environment while also ensuring structural safety.

FUTURE SCOPE

The study on Polyethylene Glycol (PEG) and nano silica incorporated concrete opens several possibilities for future research and large-scale applications in sustainable construction.

- Investigation on large-scale field applications of PCM embedded concrete in real buildings
- Study on long-term durability and aging behavior of PEG and nano silica concrete
- Development of advanced encapsulation techniques to prevent PCM leakage
- Exploration of alternative Phase Change Materials with different melting temperature ranges
- Optimization of mix design for improved balance between thermal and mechanical performance
- Integration of smart sensing systems with PCM concrete for real-time temperature monitoring
- Application in green building standards and energy-efficient infrastructure projects

Further research in this area can help in developing highly efficient, sustainable, and cost-effective construction materials suitable for modern energy-saving buildings.

SCOPE FOR PRACTICAL IMPLEMENTATION

The practical implementation of PEG and nano silica modified concrete can be extended to real-world construction projects with proper design optimization and cost evaluation. This material has strong potential in modern sustainable construction due to its dual advantage of thermal regulation and mechanical strength enhancement.

This concrete can be implemented in residential apartments, commercial complexes, and institutional buildings where energy consumption for cooling systems is high. It can also be applied in roofing systems and external wall panels to reduce heat transfer into buildings.

For large-scale adoption, standard guidelines need to be developed for PCM dosage, mixing techniques, and curing methods. Collaboration with construction industries and government initiatives can further promote the use of energy-efficient building materials.

Pilot projects and prototype buildings can be constructed to evaluate real-time performance under natural environmental conditions. This will help in validating laboratory results and improving practical feasibility.

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