**Effect of Nano Calcium Carbonate Replacement on Workability and Mechanical Strength of OPC Concrete with PET**

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**Abstract.** The ongoing expansion of the global construction industry has led to a rising demand for concrete materials. One innovative approach gaining traction is the use of nanoparticles, such as calcium carbonate (CaCO3), as a substitute for cement, aiming to reduce cement usage while providing various advantages. In this study, 5% of cement was replaced with CaCO3, and 10% of the fine aggregates were substituted with polyethylene terephthalate (PET). CaCO3 is a natural material with finer particle sizes than cement, enhancing the particle packing within the concrete and creating a spacer effect. This substitution resulted in a concrete mix with a higher slump, which improved workability. The specimens were cast in 150mm x 150mm x 150mm molds. At 28 days, the hardened concrete containing CaCO3 showed lower water absorption, as microscopy analysis revealed very low porosity in this concrete.Mechanical property tests were performed at 7, 14, and 28 days. The addition of CaCO3 contributed to increased early strength due to its accelerating effect and higher hydration rate, allowing the concrete to set more quickly. However, at full maturity, the strength of the concrete with CaCO3 was slightly lower compared to the control mix without it, although it remained within the acceptable target strength range

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# Introduction

Concrete is a key material in construction, known for its impressive technical properties and economic benefits, making it the primary choice for most structural designs in the industry. Cement is essential in concrete production, with Ordinary Portland Cement (OPC) being the most widely used type globally. However, a significant concern regarding cement is its environmental impact; cement production contributes approximately 7% of the total greenhouse gas emissions worldwide. As a binder in concrete, cement can be partially replaced by fillers, which are finely ground materials similar in fineness to cement. Alternative materials for replacing OPC in concrete are increasingly accepted due to their environmental, economic, and technical advantages. Among these alternatives, calcium carbonate (CaCO3) and polyethylene terephthalate (PET) are notable for their ability to save costs, conserve energy, and reduce carbon dioxide emissions. Incorporating CaCO3 into concrete offers substantial benefits to the construction sector, including enhanced early strength, accelerated reactions, and improved particle packing that lowers porosity.

# Experimental Details

**Material.** The material selection in this study was in accordance to specific requirement. The cement used in this project was Ordinary Portland Cement (OPC) . The brand of the OPC was ACC Cement. . The physical characteristics of the cement adhere to the specifications outlined in IS: 1489-2015, validating its compliance with the established limit shown in table 1.

**Table 1:** Physical properties of cement

|  |  |  |
| --- | --- | --- |
| **S. No.** | **Name of Test** | **Result** |
| 1 | Fineness modulus (by dry sieving) | 6.21 |
| 2 | Consistency Test | 30% |
| 3 | Initial Setting time | 48 minutes |
| 4 | Final Setting time | 310 minutes |
| 5 | Specific gravity | 3.09 |

. The brand for the Nano CaCO3was Qualigens. It was in accordance to the requirements of ISO 9001: 2000. This specification is inclusive of the quality control and characteristics inspection such as CaCO3content, fineness and particle size distribution. The main compound of CaCO3 was calcium oxide (CaO). CaCO3was extracted from quarry rocks from limestone hill, which then crushed with jaw crusher and waste was separated with raw stone of 6 x 9 inch. The crushed CaCO3 were then hammered to smaller sizes 2 to 3 inch before they were fed into roller mills. Finally they were grounded with roller mill and classified with cyclone to the right size required. While properties of PET used in the experimental work are given in table 2.

Table 2. Characteristics of PET used in the experimental work

|  |  |  |  |
| --- | --- | --- | --- |
| Grade | Density | Manufacturer | Granule Size |
| B52A003 | 0.954 g/cm3 | Gail India G-Lex | ≤ 4.75 mm |

**Mix Design.** In this study the amount of CaCO3 replacement adopted was 5%. Most of researchers have found out that 5% CaCO3  and 10% PET replacement will produced quality concrete product. The strength maintained or even increased in paste containing 10% CaCO3 [3]. In this study, two mixture proportions have been designed. The first mix proportion was the mix design with CaCO3 and PET while the other mix was without the CaCO3 and PET. The methodology was designed to analyze the effect of CaCO3 and PET replacement into concrete. Both mix designs were based on the Grade 40 concrete formulation. The number of samples prepared for this study was 18 cubes with the size of 150mm x 150mm x 150mm.

Table 3. Mixture proportion of concrete with Calcium Carbonate (CaCO3) and PET replacement

|  |  |  |
| --- | --- | --- |
| **Materials** | **With CaCO3 addition (kg)** | **Without CaCO3 addition (kg)** |
| Ordinary Portland  Cement (OPC) | 15.01 | 15.80 |
| Calcium Carbonate  (CaCO3) | 0.79 | 0 |
| Fine Aggregate | 28.05 | 31.17 |
| PET | 3.12 | 0 |
| Coarse Aggregate | 46.31 | 46.31 |
| Water | 8.34 | 8.34 |

**Cement Preparation and Characterization.** OPC and CaCO3 were mixed in a dry condition. The mixture machine was switched on and wetted with water. The course aggregate and fine aggregate with PET were carefully poured into the mixer followed by pouring of 75% amount of water. The mixer was rotated for 8 minutes before the mixture of OPC and CaCO3 were poured into the mixer followed by the remaining water. The mixture was rotated for a few more minutes until the mixture was cohesive. Then, the fresh concrete was placed into a wheelbarrow before casting into the moulds. Workability and consistency of fresh concrete were analyzed with slump test. The fresh concrete was cast into the mould and compacted with using steel rammer and vibrated by using vibrator machine. The concrete cubes were left in the laboratory for 24 hours, before curing in curing tank for 28 days.

The tests carried out were material characterization, physical properties test and mechanical properties test. For material characterization, X-ray Diffraction (XRD) and Scanning Electron Microscopy (SEM) techniques were used. For physical properties test, workability was measured by slump test and the rate of water absorption was measured by using BS 1881: 122. For water absorption test the concrete was oven dried at 105oC for 48 hours. The initial weight of the concrete cubes was taken. Then, the concrete cubes were placed in water for 24 hours before the final weight of the cubes was taken. Rate of water absorption was calculated by the percentage difference of weight divided by initial weight. For mechanical properties test, the compressive strength was determined using compression test machine for 150 mm cubic sample.

# Results and Discussion

**Material Characterization and Physical Properties Test**. CaCO3 and OPC mixed with PET were characterized using SEM to analyze their morphology, microstructure, and particle size. Figures 1 illustrate the microstructures of CaCO3 and OPC, showing that CaCO3with PET displays irregular and agglomerated circular shapes, attributed to the grinding of natural limestone. In contrast, OPC mainly consists of irregularly shaped amorphous particles, resulting from inter-particle fusion during rapid cooling and grinding processes. The particle size of CaCO3 is predominantly below 5 µm, while OPC particles are slightly larger, mostly under 10 µm. The fine CaCO3 particles act as fillers between OPC, enhancing the packing density of the concrete and reducing porosity and air voids.Figure 2 presents the XRD analysis of CaCO3 , where the highest reflection peak at 2θ = 27° corresponds to the (62) plane, indicating the calcite structure of CaCO3, which is primarily composed of calcium oxide (CaO). Calcite has a rhombohedral structure and is the most stable form of CaCO3 at room temperature.Tables 4 and 5 indicate that the slump value for fresh concrete with CaCO3 was higher than that of OPC. The greater cohesiveness of CaCO3 concrete is due to the fine particles optimizing water absorption, promoting complete hydration and enhancing the uniformity of the mix. This effect is linked to the fineness of the CaCO3 powder, which helps disperse cement clusters, allowing for better lubrication of aggregates and improved workability. Filler particles reduce voids and enhance the packing of the mix, contributing to a higher slump.At 28 days, the water absorption rate for concrete without CaCO3 was higher than that of the concrete with CaCO3 . The presence of fine CaCO3 particles minimizes internal pores through better packing, resulting in lower water absorption. Filling voids within the packed system improves particle arrangement, enhancing the interface's contribution to reducing mixture absorption. This lower water absorption can be attributed to a stronger aggregate-matrix bond formed by a less porous transition zone in the CaCO3 concrete.

 

Fig. 1. Microstructure of raw materials Calcium Carbonate (CaCO3) with PET.

Fig. 2: XRD analysis of Calcium Carbonate (CaCO3).

Table 4. Average slump value

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|  |  |
| --- | --- |
| **Materials** | **Average Slump Value (mm)** |
| 100 % OPC | 72 |
| 95 % OPC + 5 %  CaCO3 with PET | 113 |

Table 5. Rate of water absorption of concrete at 28 days.

|  |  |
| --- | --- |
| **Materials** | **Average Rate of Water Absorption (%)** |
| 100 % OPC | 1.5728 |
| 95 % OPC + 5 %  CaCO3 with PET | 1.2137 |

**Compression Test**. The results of the compressive strength which were performed in accordance to the procedure. The figure shows the average results at 3, 7 and 28 days test for concrete with and without partial replacement of CaCO3 and PET.The concrete with CaCO3 content exhibits higher compressive strength at early concrete age of 3 days and 7 days compared to 100 % OPC concrete. This occurs due the filler effect of CaCO3, so better distribution of cement particles provides more complete hydration reaction at the optimum water requirement for high early strength achievement. Additionally, CaCO3 fillers reacted with C3A phase of cement and support the formation of carboaluminate that partially takes part of ettringite which increase the early strength of concrete [8]. The compressive strength of OPC concrete is higher than the CaCO3 concrete at 28 days, which is when the concrete reach maturity. As the reactive cement is being replaced with a relatively inert CaCO3, it would be expected that some decrease in compressive strength would occur in the system with CaCO3 replacement for cement. This also occurs due to very little reaction between CaCO3 with cement hydrates to substitute the pozzolanic activity for long term effect.

Fig. 3. Compressive strength prepared using OPC (NC0)only and OPC with CaCO3 with PET (NC5)

# Conclusion

The results indicate that CaCO3 particles are finer than OPC and they act as filler in the concrete mixture. The slump of CaCO3 concrete is higher than OPC concrete, which resulted in better workability. The water absorption rate for CaCO3 concrete is lower than OPC concrete. This is due to the presence of nano CaCO3 particles which reduce the pores inside the concrete, thus create better packing of particle between cement and CaCO3. At early age, the CaCO3 concrete produces higher compression strength than the OPC concrete due to higher hydration rate and accelerator effect. However at 28days the compression strength is a little lower than the OPC concrete.

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