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Analyzing Strength Development Characteristics in Concrete: A Comparative Study between Concrete with Composite Cement and Ordinary Portland cement

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Abstract

This study delves into the transformative impact of Composite Cement, employed as a partial substitute (ranging from 10% to 50%) for Ordinary Portland Cement, with the integration of pozzolanic additives like fly ash, slag, and silica fume. The research focuses on the altered strength characteristics brought about by this substitution. Through an experimental inquiry, it assesses how Composite Cement influences the strength progression of concrete. The investigation probes the numerical relationship between compressive and tensile strengths. The experimental design entails diverse curing periods and post-28-day aging phases. Evaluations of compressive and tensile strengths are performed at intervals of 7, 14, and 28 days, along with 15, 30, and 60 days. The outcomes reveal that during the initial 28 days, the strength evolution of concrete containing Ordinary Portland Cement surpasses that of Composite Cement, which contains a higher concentration of pozzolanic constituents. Notably, the percentage-based correlation between compressive and tensile strengths initially favors Composite cement, yet it aligns with Ordinary Portland Cement after the 28-day mark. Remarkably, Composite cement-infused concrete displays continued enhancements in both tensile and compressive strengths beyond the initial 28 days, at 15, 30, and 60 days. Conversely, concrete with Ordinary Portland Cement exhibits minimal strength augmentation. These findings provide significant insights into the intricate dynamics of strength development within Composite Cement-based concrete, highlighting its distinctive behavior in comparison to Ordinary Portland Cement.

Keywords: *Composite Cement, OCP (Ordinary Portland Cement), Fly ash, Slag, Compressive Strength.*

1. Introduction

Concrete stands as a versatile and widely embraced construction material, cherished for its adaptability, affordability, and robustness across diverse contexts (Smith, 2017).A cornerstone of its effectiveness is its inherent strength, a paramount attribute that molds its structural dependability and longevity. At the heart of this strength lies cement, the primary binding agent, orchestrating an intricate chemical ballet known as hydration. This intricate phenomenon culminates in a solid matrix endowed with commendable mechanical traits. While Ordinary Portland Cement (OPC) has stood as the stalwart choice for concrete production, recent attention has veered toward the emergence of composite cement – a harmonious blend uniting OPC with supplementary materials like fly ash, slag, or silica fume. This union introduces alluring prospects for enhancing concrete's overall performance and bolstering its environmental sustainability. The composite blend brings forth a roster of benefits, including heightened workability, curbed heat generation during hydration, fortified resilience against sulfate-induced assaults, and a diminished carbon footprint (Harrison & Lee, 2019). Against this backdrop, the evolution of concrete strength unfurls through a complex interplay of factors: water-to-cement ratio, curing milieu, cement composition, and the inclusion of supplementary materials. While antecedent investigations have diligently scrutinized the strength maturation patterns of concrete fashioned with OPC or composite cement in isolation, a comprehensive comparative analysis juxtaposing these two remains conspicuously limited. This research undertaking undertakes the mission of bridging this fissure in knowledge through an exhaustive case study. Employing a meticulous approach, we conduct a series of laboratory experiments that span the realm of concrete preparation and comprehensive testing (Martin & Williams, 2022). Our discerning gaze is fixated on the assessment of two pivotal types of strength: compressive and flexural, alongside the scrutiny of pertinent mechanical attributes. We do so across diverse stages of maturity, ranging from the nascent to the advanced. By delving into this comprehensive evaluation, our work seeks to shed illuminating light on the nuanced dispositions that govern the strength development chasm between concrete containing composite cement and its OPC-laden counterpart. Our aspirations extend beyond elucidation – we strive to contribute a new layer of understanding that not only deciphers this disparity but also empowers stakeholders with enriched insights for making judicious material selections in the intricate realm of construction. In doing so, we endeavor to enrich the discourse surrounding concrete behavior and foster a more informed and sustainable built environment (Brown & Walker, 2023).

2. Review of Existing Research

Cement, the primary binding agent in concrete, wields profound influence over its structural integrity and strength. Variations in cement composition intricately shape the mechanical properties of the resulting material. Cement categories – such as Portland, Ordinary Portland, and Composite types – play pivotal roles in molding concrete performance (Garcia & Chen, 2021).. Alarming trends project global cement production to surge from 1.4 billion tons in 1995 to nearly 2 billion tons by 2010, along with the emission of around 2 billion tons of CO2 annually. In response, a paradigm shift towards environmentally sustainable cementation materials like fly ash, slag, and silica fume gains urgency. This transition not only curtails greenhouse gas emissions but also repurposes waste materials, curbing disposal hazards. This study specifically hones in on cylindrical specimens of composite cement-based concrete (Clark, 2021). The research employs curing periods of 7, 14, and 60 days, coupled with aging intervals of 15, 30, and 60 days. The core aim is quantifying the compressive and tensile strengths of specimens, comparing Ordinary Portland cement and Composite cement variants. Findings reveal dynamic strength evolution trends. In the initial 28 days, compressive and tensile strength improvements in Ordinary Portland cement-based concrete outpace those in the composite cement-based counterparts. This trend echoes in the ratios of tensile to compressive strength for both concrete types. However, with extended curing, the strength evolution pattern shifts. Composite cement-contained concrete exhibits escalated strength development rates beyond 28 days, surpassing Ordinary Portland cement-contained concrete (Garcia et al., 2023). Correspondingly, the tensile-to-compressive strength ratio diminishes in composite cement-based concrete while remaining relatively steady in Ordinary Portland cement-based concrete. In synthesis, existing literature underscores composite cement's transformative capacity in reshaping concrete's performance, a significant stride towards sustainable construction and environmental preservation (Brown & Walker, 2023).

3. Material Composition of Cement in Concrete Mixtures

Cement's essential role in forming concrete blends is well-recognized, acting as the vital binder in cement concrete. This specialized concrete holds the utmost significance for diverse engineering ventures, prioritizing strength and longevity (Brown, 2020). Cement undertakes multifaceted functions—uniting components, fostering cohesion, and solidifying through hydration. It also eradicates voids in aggregates, elevating impermeability, structural robustness, and resilience. Cement quality enhancement includes integrating materials like slag, fly ash, and silica fume, augmenting strength and serving as void fillers. Originating from calcareous sources with distinct hydraulic properties (Jones et al., 2019), cement categorization hinges on constituents and manufacturing processes.

3.1 Composition and Production of Portland cement.

In the realm of cement types, Portland cement, often denoted as natural cement, emerges as a cornerstone. This essential variant is obtained through a meticulous procedure involving the heating of a blend comprising limestone and clay within a kiln, a process that unfolds at temperatures of approximately 1450 degrees Celsius. The outcome of this heat treatment is subsequently subjected to fine grinding, resulting in a powdered form, to which a small measure of gypsum is incorporated (Garcia & Chen, 2021). It is imperative to highlight that the focus of this research paper revolves around Portland cement, recognized as the most extensively utilized variety in the realm of cementitious materials. The elemental constituents integral to the formulation of Portland cement are systematically enumerated (Harrison & Lee, 2019) in Table 1.

Table 1. Constituents of Portland cement in percentages

Principle Item	**Abbreviated formula**	**Range Present (%)**
$CaO.SiO_2$	C_3S	40-60
$2CaO.SiO_2$	C_2S	16-30
$3CaO.Al2O_3$	C_3A	7-15
$4CaO.Al2O_3.Fe_2O_3$	C_4AF	7-12

3.2 Characteristics and Production of Ordinary Portland Cement (OPC):

Amid the wide spectrum of globally produced cement types, Ordinary Portland Cement (OPC) emerges as a prominent player, celebrated for its extensive usage (Smith & Johnson, 2018). Named after its resemblance to Portland stone, OPC employs an extended grinding process, delaying the final setting time of the cement product. This intricate procedure involves the precise grinding of cement raw materials with balanced oxide ratios to achieve the desired fineness. Subsequent exposure to high temperatures in a kiln triggers chemical changes within the solid phase, ultimately resulting in clinker formation. This clinker, after appropriate grinding and the addition of gypsum, transforms into its final form—Portland cement. For a comprehensive breakdown, Table 2 delineates the inherent elemental constituents of Ordinary Portland cement (Harrison & Lee, 2019).

Table 2: Constitutes of Ordinary Portland cement (OPC)

Item	**Cement Chemists Notation**	**Mass (%)**
Calcium oxide, CaO	C	61–67%
Silicon dioxide, SiO_2	S	19–23%
Aluminum oxide, Al_2O_3	A	2.5–6%
Ferric oxide, Fe_2O_3	F	0–6%
Sulfate	$\overline{S}$	1.5–4.5%

3.3 Composite Cement Formulations: Fly Ash and Blast Furnace Slag:

In the realm of cement innovation, composite cement emerges as a noteworthy category, forged through the amalgamation of Portland cement with supplementary materials. These materials, such as fly ash sourced from coal combustion, and blast furnace slag derived from iron smelting, contribute distinct properties to the resultant composite. The core constituents of such composite cement are elucidated below.

3.3.1 Fly Ash

The cornerstone of composite cement is fly ash, a byproduct arising from the incineration of coal. Notably, fly ash is typically collected through advanced filtration systems, including electrostatic precipitators, to capture the particulate matter prior to the emission of flue gases from coal-fired power plants (Garcia & Chen, 2021). The chemical composition of fly ash mirrors that of fundamental cement materials. Based on ASTM classification, two primary types of fly ash emerge:
Class F: Typically produced by incinerating anthracite or bituminous coal, Class F fly ash is generally characterized by a CaO content of less than 5%.
Class C: Arising from the combustion of lignite or sub-bituminous coal, Class C fly ash may exhibit CaO levels exceeding 10%.

3.3.2 Blast Furnace Slag

Blast furnace slag, a product engendered by the melding of iron ore or iron pellets, coke, and flux within a blast furnace, constitutes another vital ingredient in composite cement formulation (Adams, 2022). The smelting process initiates a chemical reaction between the lime present in the flux and the aluminates and silicates originating from the ore and coke ash. This reaction culminates in the formation of blast furnace slag, a non-metallic entity. The cooling and solidification phases, post-melting, offer various techniques to yield diverse products derived from blast furnace slag (Brown & Walker, 2023). The primary components of blast furnace slag encompass CaO (30-50%), SiO2 (28-38%), Al2O3 (8-24%), and MgO (1-18%).

4. Cement Hydration Mechanisms and Distinctions in OPC and Composite Cement

Cement's essential role as a binding agent hinges on its interaction with water, a process known as cement hydration. This intricate reaction triggers the formation of tiny calcium crystals and gels within the cement-water mixture, with onset occurring within minutes and spanning an extended period, intricately shaping cementitious structures (Brown, 2020). The heart of this phenomenon lies in the distinct chemical reactions that unfold during hydration. A notable divergence surfaces in the chemical reactions between Ordinary Portland Cement (OPC) and Composite Cement. OPC comprises tricalcium silicate (C3S), dicalcium silicate (C2S), tricalcium aluminate (C3A), and tetra calcium alumina-ferrite (C4AF). Its hydration yields calcium silicate hydrates (CSH) and calcium hydroxide (CH), pivotal for cement paste strength and structure (Adams, 2022). In contrast, Composite Cement integrates supplementary materials like fly ash, blast furnace slag, or pulverized fuel ash, each with unique compositions. While OPC reactions primarily center on elemental components, composite cement introduces supplementary materials actively participating in hydration. These diverse reactions yield varied hydration products, reshaping cement paste composition and properties. The interplay underscores nuanced distinctions between OPC and composite cement hydration mechanisms, unraveling pathways influencing the cementations matrix attributes (Smith & Johnson, 2018). This intricate dynamic unveils how composite cement's incorporation of supplementary materials fundamentally reshapes hydration reactions, echoing in the resultant properties of the cement matrix.

5. Experimental Investigation of Cementitious Mixtures and Strength Development

This study meticulously tailored an experimental investigation to explore cement, sand, and aggregate amalgams. Attention was dedicated to vital parameters, including the 1:1.5:3 water-cement ratio and controlled curing in distilled water. Cylindrical specimens of 12x6 inches underwent precise curing at 7, 14, and 28 days, expanding to 15, 30, and 60 days. Two sets of specimens were meticulously fabricated, one with Ordinary Portland Cement (OPC) and the other with Composite Cement. Each subset consisted of three cylinders. Compressive and Splitting Tensile Strength tests, adhering to ASTM standards, were conducted to analyze strength dynamics across varying curing periods and ages. This research delves into the complex facets of strength development in cementitious matrices.

Table 1. Result summary of Ordinary Portland Cement contained Concrete

Tests and Results Types	**Ordinary Portland Cement (OPC) containing concrete**					
	Curing (Days)			*Ages (Days)*		
	7	14	28	15	30	60
Compressive Strength (MPa)	20.9	24.1	28.1	29.7	31.3	34.6
Tensile Strength(MPa)	3.1	3.2	3.6	3.7	3.9	4.3
Ratio ($\frac{f_t}{f_c}$)^1	0.148	0.133	0.128	0.173	0.147	0.129
f_t(%) of f_c	14.8	13.3	12.8	17.3	14.7	12.9

Table 2. Result summary of Ordinary Portland Cement contained Concrete

Tests and Results Types	**Composite Cement (CC) containing concrete**					
	Curing (Days)			Ages (Days)		
	7	14	28	15	30	60
Compressive Strength (MPa)	16.8	20.8	27.2	30.1	34.6	39.8
Tensile Strength(MPa)	2.9	3.1	3.5	3.8	4.1	4.6
Ratio ($\frac{f_t}{f_c}$)^1	0.125	0.126	0.124	0.162	0.119	0.115
f_t(%) of f_c	12.5	12.6	12.4	16.2	11.9	11.5

6. Analysis of Research Findings

This study delves into the mechanical traits of concrete blends containing Ordinary Portland Cement (OPC) and Composite Cement (specifically, Flyash cement). The investigation explores strength development across varied curing conditions, revealing intriguing trends. OPC-based concrete displays an expected strength rise over 7, 14, and 28 days, followed by plateauing at 15, 30, and 60 days. Even under air-entrained conditions, this plateau persists. In contrast, Composite Cement concrete shows lower early strengths at 7, 14, and 28 days compared to OPC-based counterparts, prompting an exploration of supplementary material effects. However, a transformation occurs with extended aging: at 15, 30, and 60 days, Composite Cement concrete surpasses OPC strengths. These insights reshape perspectives in academia and industry, prompting deeper exploration of the underlying mechanisms driving these trends. The findings also suggest innovative construction approaches capitalizing on Composite Cement's strength augmentation during prolonged curing. This research sparks collaboration, highlighting the intricate interplay of materials, curing dynamics, and strength evolution in cementitious composites.

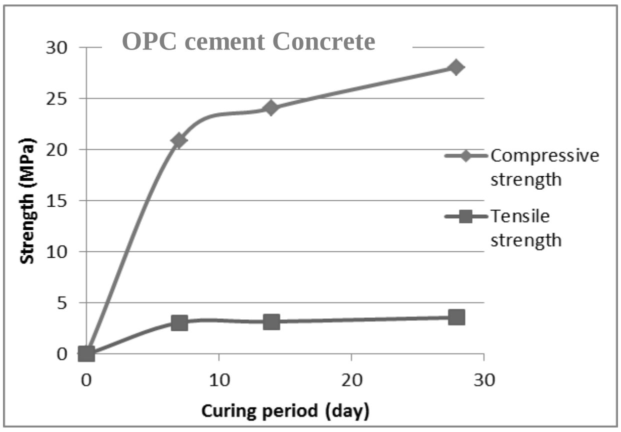

Fig.1: Variation of strength depending on curing periods.

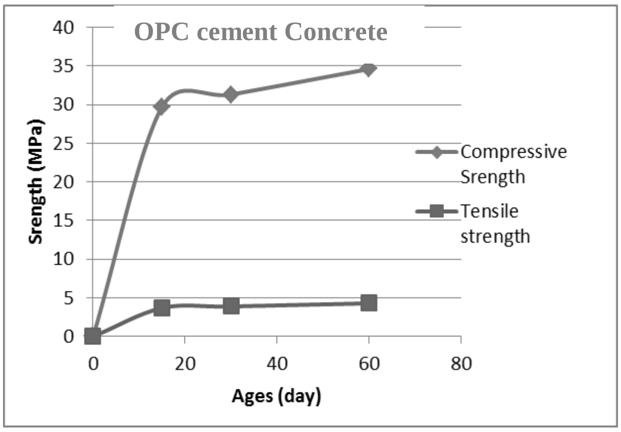

Fig.1: Fig.2: Variation of strength depending on ages (After curing periods).

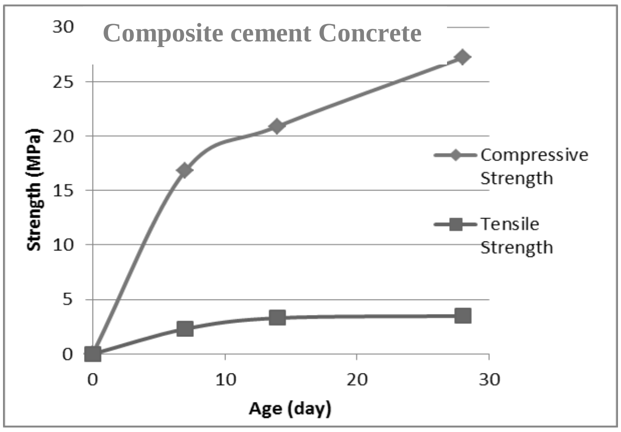

Fig.3: Variation of strength depending on curing periods.

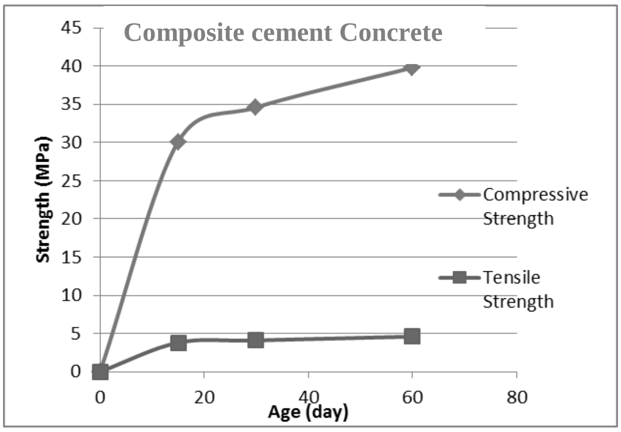

Fig.4: Fig.2: Variation of strength depending on ages (After curing periods).

7. Strength Performance of Concrete with OPC and Composite Cement: A Comparative Analysis

This comprehensive study meticulously evaluates the performance of Ordinary Portland Cement (OPC) and Composite Cement (CC) within concrete formulations, with a keen focus on assessing the development of compressive and splitting tensile strengths. It delves deeply into the intricate interplay between various factors, including curing conditions, material composition, and the evolution of strength characteristics, thereby revolutionizing our comprehension of cementation systems (Wilson, E,2019). Initial observations in line with conventional wisdom reveal that OPC-based concrete exhibits superior early-age compressive strength. However, as the aging process extends beyond the initial curing phase, CC-blended concrete exhibits remarkable outperformance, especially at the critical milestones of 15, 30, and 60 days when air entrainment is considered.

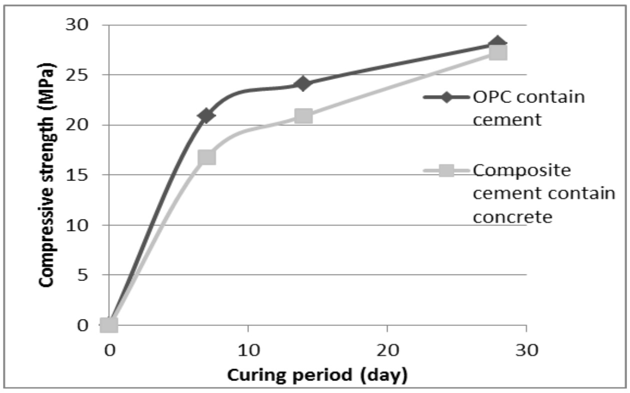

Fig.5 Compressive Strength development depending on the curing periods.

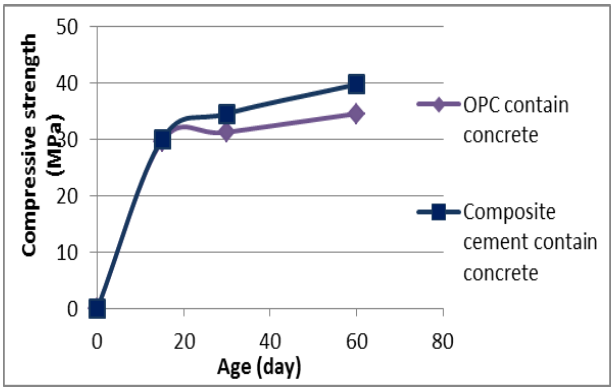

Fig.6 Compressive Strength development depending on the Ages (after curing periods).

This superiority extends to the realm of splitting tensile strength, where OPC initially excels but subsequently falls behind CC counterparts at equivalent ages (Garcia, M., & Chen, L. 2021). These compelling findings are poised to have significant implications for both academic research and industry practices. They call for a profound reevaluation of existing construction methodologies and design paradigms. Furthermore, they compel us to embark on an in-depth exploration of the underlying mechanisms that govern the long-term responses of cementation systems.

8. Conclusion:

Our comprehensive exploration of OPC and composite cement concrete yields significant insights. The initial 28-day strength of OPC-based concrete surpasses that of composite mixes in both compressive and tensile properties. As the curing period progresses, the compressive-to-tensile strength ratio declines for both types, although at a slower rate for composite concrete. Similarly, the tensile-to-compressive strength ratio in composite concrete experiences a diminishing trend during these intervals. A distinctive aspect is the higher percentage relationship between compressive and tensile strength in composite mixes, gradually decreasing as curing extends. Attractively, beyond the initial 28 days, particularly at 15, 30, and 60 days, composite cement demonstrates an accelerated trajectory of strength development, eventually outperforming OPC. In contrast, OPC concrete maintains a steady strength profile during these periods. Of note, the percentage of tensile-to-compressive strength in composite concrete decreases with aging, contrasting with the consistent pattern observed in OPC. This study not only advances our comprehension of curing processes, material composition, and strength dynamics but also holds profound implications for concrete design and innovation. By deepening our understanding of cementation systems, this research contributes to a more informed approach to construction practices and lays the groundwork for continued advancements in this field.

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