

Enhancing Mechanical and Durability Performance of Composite Material Using Egg Shell Powder and Copper Slag

D.R. Naxine¹*, Sujesh Ghodmare²

Abstract

This research aims to investigate the use of copper slag (CS) and Egg Shell Powder (ESP) as partial substitutes in polymer composite to enhance mechanical properties and durability. Considering that the construction sector is recognized for consuming a significant amount of resources in comparison to other industries, its further expansion poses a direct danger to resource availability. This could disrupt ecosystems, lower biodiversity, and have an effect on riverine and coastal areas, which are common sources of sand. The goal is to minimize their usage, diminish pollution, and alleviate pressure on natural resources. The CS is a by-product of copper extraction and refining processes which composed of iron and silica more than 70-80%. The production of ESP from households, hotels, residential areas and from different factories contributes to environmental degradation and it contains 94-95% calcium carbonate. Thus, ESP and CS act as filler material polymer composite. Polymer composites were formulated, incorporating ESP replacement rates of 5% and 7.5% for cement, along with CS replacement rates of 40% and 60% for sand. The results show that when copper slag increases, water absorption reduces. The study's findings indicated that the best combinations considerably increased compressive strength and reduced water absorption. Optimal combinations significantly improved compressive strength and reduced water absorption.

Keywords: Copper Slag (CS), eggshell powder (ESP), hybrid composite, compressive strength, mechanical properties, composite materials

INTRODUCTION

Concrete is widely used to build roads, bridges, pavements, dams, tunnels, and buildings due to its strength and durability [Maharishi Abhishek et.al] [1]. Both urban and rural residential buildings, including single-family homes and apartment buildings, frequently use concrete as a building material [Nandhini K.et.al] [2]. Concrete is often used for structural components and facades of skyscrapers, business buildings, hotels, and shopping centres [Yang Dawei et.al] [3]. Because of its long lifespan and immediate capacity to support heavy loads, concrete is an essential part of transportation infrastructure, including runways for airports, railroad sleepers, and highways [Reddy Yasa Manohar et.al] [4]. Given the significant resource consumption attributed to the construction industry compared to other sectors, its continual expansion presents a tangible threat to resource availability [Mohamed Amin et.al] [5]. Furthermore, the creation of industrial waste and by-products across multiple industries exacerbates potential dumping issues. In India, the main difficulty is the use of industrial products in polymer composites and composite concrete or hybrid composites, which contribute significantly to environmental damage

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Received Date: April 17, 2024

Accepted Date: July 01, 2024

Published Date: September 23, 2024

Citation: D.R. Naxine, Sujesh Ghodmare. Enhancing Mechanical and Durability Performance of Composite material using Egg Shell Powder and Copper Slag. Journal of Polymer & Composites. 2024; 12(6): 1–7p.

[Saleh Ali Said Al Abri et.al] [6]. Addressing this issue will entail the implementation of recycling and reuse procedures across construction sites and sectors, providing a sustainable solution by using copper slag (CS) as sand and egg shell powder (ESP) as cement [Kurien, R.A. et.al] [7]. Sand is a limited resource that becomes depleted when usage exceeds sustainable levels [Chandar Prakash S. et.al] [8]. This can have an impact on natural habitats, upend ecosystems, and lessen biodiversity in riverine and coastal regions, which are common sources of sand. CS is a by-product formed by the smelting and refining of copper ore [Blasius Ngayakamo et.al] [9]. It is a granular material that is composed mostly of iron, silica, and trace elements, depending on the ore source and refining process. Its smooth, glassy surface enhances concrete workability and strength, rendering it a viable alternative for fine aggregate in construction. For instance, ESP can be extracted from discarded eggshells, abundant in households, restaurants, and hotels [Palanisamy S. et.al] [10]. In urban locations or large-scale food processing plants where there is a high volume of egg consumption, improper recycling or composting of egg shells can exacerbate waste management issues. Salmonella bacteria and other diseases may be present in egg shells, particularly if they are not thoroughly cleaned before being disposed of or recycled [Sohu S et.al] [11]. Inappropriate handling or incorrect use of tainted egg shells in composting or gardening can put human health and the environment at risk. ESP primarily composed of calcium carbonate (CaCO_3), with trace amounts of proteins and other minerals [Karuppiyah G. et.al] [12]. Given their lack of practical use in daily life, these eggshells often contribute to pollution. Incorporating CS and ESP into construction practices not only minimizes waste generation but also promotes more sustainable and eco-friendly building methodologies [Naxine Dhiraj et.al] [13]. This work intends to investigate the application of CS and ESP in polymer composites to achieve desirable mechanical properties, despite their underutilization.

LITERATURE SURVEY

Numerous studies have explored alternatives for substituting various components of concrete [Chen Y.K et.al] [14]. It is recommended to incorporate copper slag up to 40% of the natural fine aggregates to achieve concrete with robust strength and durability [Palanisamy, S. et.al] [15]. Furthermore, a combination of 10% ESP and 90% cement yielded higher compression values [Jhatial A.A et.al] [16], with consistent substitution of the fine aggregate portion with CS resulting in strength improvements, particularly at a ratio of 15% CS and 85% sand [Mylsamy Bhuvaneshwaran et.al] [17]. Additionally, several researchers have observed strength enhancements with the utilization of ESP up to 6% and CS up to 40% [Kumar, P.C. et.al] [Karthik A. et.al] [18,19].

MATERIALS AND METHODOLOGY

We procured Ordinary Portland Cement (OPC), which adheres to the Indian Standard IS-12269, from a nearby vendor. OPC cement is widely employed in construction projects throughout India [Tie I. M. W. et.al] [20]. We obtained coarse aggregate (20 mm nominal size) from a supplier and incorporated it into the polymer composite (Tables 1–3). We acquired the fine aggregate from the closest river, ensuring it met the Zone-II grade specifications required for the experimental procedures. We procured egg shell powder from an online vendor and obtained ESP from an online supplier. Industrial by-product CS was acquired from a supplier in Surat, Gujarat. It is meant to be used as an alternate material in composite mixture [Shcherban E.M. et.al] [Mansoor S. S. et.al] [21, 22].

Table 1. Different Properties of Egg Shell Powder & Cement.

Property	Value of OPC used in work	Value of ESP used in work
Setting Time(Initial in min)	53.0	48.0
Setting Time (Final in min)	360	330
Consistency in	33.0	35.0
Fineness in %	8.5	7.0
Specific Gravity	3.15	2.4
Soundness	2.5	3.0

Table 2. Different Properties of Copper Slag & Fine Aggregate.

Properties	Results Obtained	
	<i>Fine Aggregate</i>	<i>Copper Slag</i>
Type	<i>Natural</i>	<i>Air Cooled</i>
Specific Gravity	2.45	3.5
Bulking	5.23 %	1.9-2.4
Bulk Density (Dry Loose)	1460 (Kg/m ³)	1886 (Kg/m ³)
Fineness Modulus	3.16	3.27
Water Absorption in %	1.5	0.18
Texture of Surface	Smooth	Glassy
Shape of Particle	Rounded	Irregular
Grade Zone ,Based on percentage passing 0.60 mm	Zone- II	Zone-II

Table 3. M20 and M25 grade of concrete mixes.

Name of Concrete	Grades of Concrete	ESP (%)	Copper Slag (%)
CC-1	M20	0	0
CC-2	M25	0	0
C-1	M20	5	40
C-2		5	60
C-3		7.5	40
C-4		7.5	60
C-5	M25	5	40
C-6		5	60
C-7		7.5	40
C-8		7.5	60

Physical Properties

Following a comprehensive analysis of OPC, ESP, fine aggregate (Sand), and industrial by-product CS properties, the construction project progressed to formulate M20 and M25 grade concrete mixes. These Composite Materials included partial replacements of standard cement and sand (fine aggregate) components with egg shell powder and (CS) copper slag. The purpose of this polymer composite design was to study the possible advantages of using ESP as a cement substitute and CS as a sand substitute. The project used this experimental methodology to evaluate the mechanical characteristics and overall performance of polymer composite that included ESP and CS. Results obtained while testing these. Hybrid Composite blends would offer valuable insights into the feasibility [Oripov Oybek et.al] [23] and potential advantages of integrating such alternative materials into future construction endeavours [Revathi S.et.al] [Ojha, Singh et.al] [24, 25].

Methodology

The properties and performance of ESP and industrial by-product CS were evaluated. The concrete mix design was executed in accordance with the guidelines stipulated in IS 10262:2019. Quantities of cement, ESP, coarse aggregate, sand and industrial by-product CS were computed based on the prescribed proportions for M20 and M25 grade composites. To ensure the workability of the concrete, water/cement ratio of 0.55 was employed for M20 and 0.5 for M25 composite concrete, selected to achieve the desired strength and consistency in the hybrid composites. Specimens were prepared and

tested as per IS 456:2000 standards, utilizing standard size cubes for sample preparation. Polymer composite preparation involved the use of a concrete mixer to thoroughly blend all components, while a tamping rod was employed to ensure uniformity and proper compaction of each concrete layer during the process. Compressive strength testing was carried out on the hardened concrete samples after specific curing durations of 7 days, 14 days, and 28 days. The results of the compressive strength tests on composite material performed at each curing interval provided vital information about the concrete's strength and load-bearing capabilities. By analysing and comparing the results across different concrete mixes (M20 and M25) and considering the impact of partial cement replacement with ESP and sand replacement with CS, this study aimed to assess the potential advantages and limitations associated with integration of these alternative materials in composite material.

RESULT AND DISCUSSION

After 28 days of curing, compressive strength tests were conducted on both conventional concrete and polymer composites specimens incorporating ESP and CS. The results indicated an increase in mechanical properties for composite material where the cement was partially substituted with ESP and fine aggregate was partially replaced with copper slag. This enhancement in compressive strength highlights the positive impact of integrating ESP and CS as partial replacements in composite material. These alternate materials likely contributed to improved cohesion and reduced porosity within the concrete, leading to enhanced strength mechanical properties. The durability checked after 90 days (Figures 1–4) The findings suggest that utilizing ESP & CS as substitutes for cement & fine aggregate respectively could serve as an effective and sustainable approach to enhancing overall composite material performance.

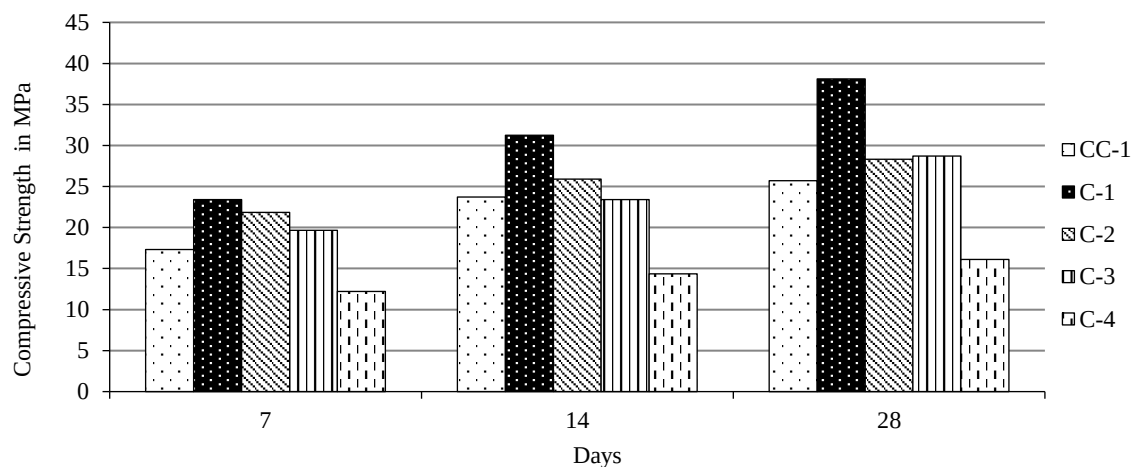


Figure 1. Compressive strength of M20 concrete without & with ESP & Copper Slag.

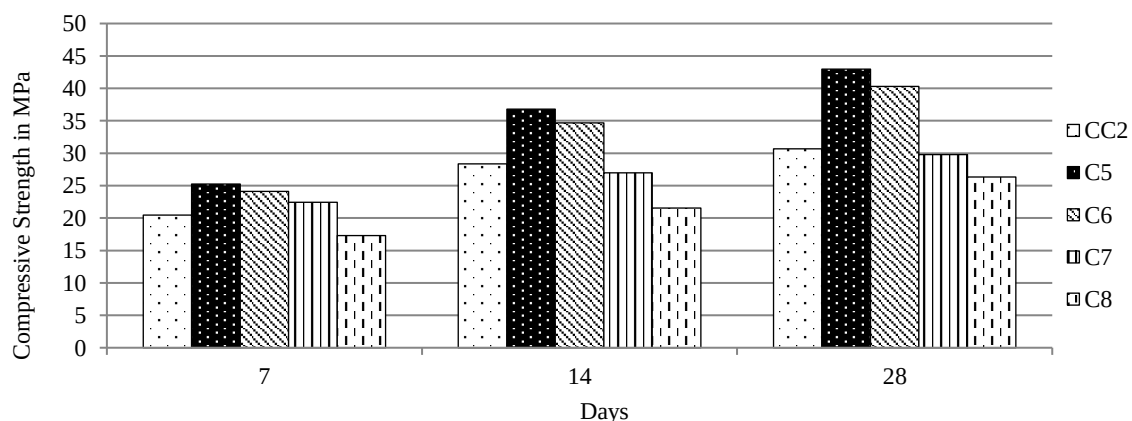


Figure 2. Compressive strength of M25 concrete without & with ESP & Copper Slag.

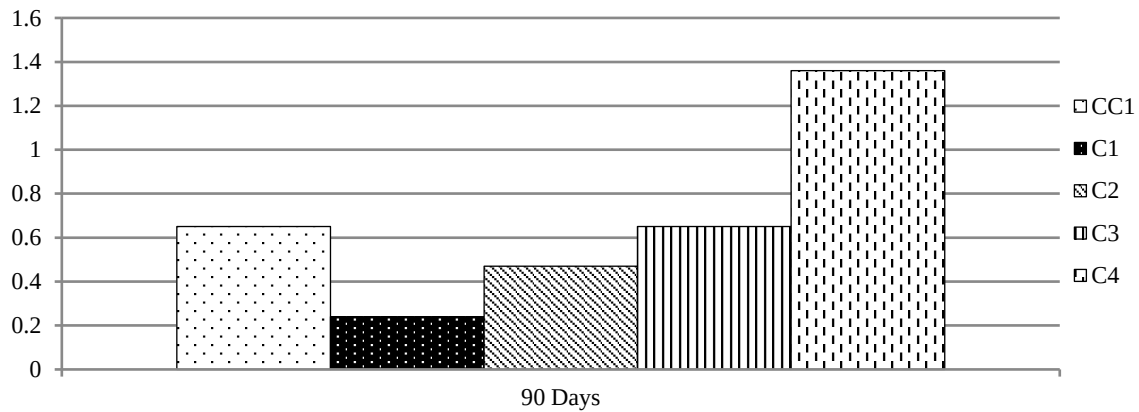


Figure 3. Water absorption (%) of M20 Concrete with ESP & Copper Slag.

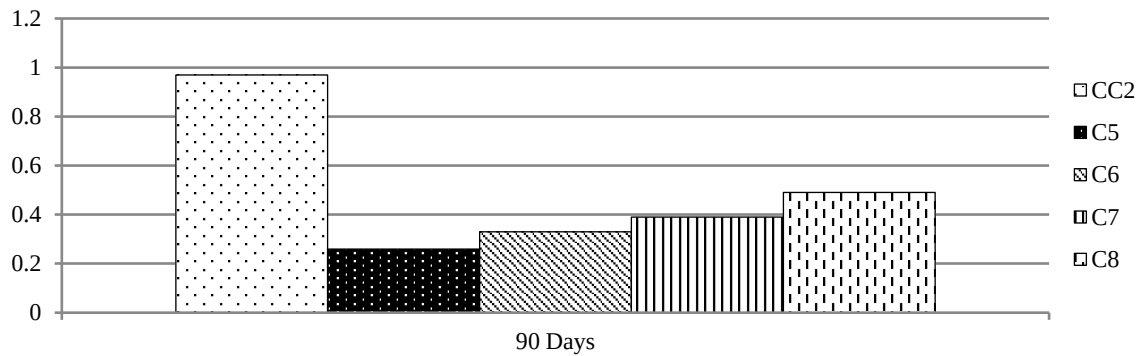


Figure 4. Water absorption (%) of M20 Concrete with ESP & Copper Slag.

CONCLUSION

In conclusion, the experimental examination of performance and properties by including ESP and CS as alternatives for cement and sand in composite material yielded the following results:

- The mechanical properties (compressive strength) of the concrete improved by up to 5% with the presence of ESP. However, when ESP content was increased to 7.5%, compressive strength decreased in contrast to normal concrete. This indicates that an optimal replacement percentage of 5% offers the most favorable outcomes in terms of compressive strength. Partially replacing sand with 40% Copper slag led to an increase in concrete strength, indicating the beneficial effects by using CS as a substitute material. However, when percentage of CS was increased to 60%, compressive strength declined, suggesting that a lower replacement percentage (40%) is more suitable for achieving higher strength.
- A hybrid composite of 5% and 7.5% ESP, combined with 40% CS, resulted in increased concrete strength. In contrast, including 60% CS together with ESP reduced compressive strength of polymer composite. This underscores significance of meticulously optimizing replacement percentages to attain the desired concrete properties.
- The addition of up to 5% ESP reduced water absorption, but it increased after adding more than 5% ESP. The results reveal that water absorption in composite materials diminishes when both cement and fine aggregate are partially replaced with 5% ESP and 40% CS.

In summary, the study suggests that, with suitable replacement ratios, ESP and copper slag present a compelling opportunity for improving performance of composite material in construction projects. Nonetheless, it's essential to meticulously determine the replacement ratios to achieve optimal outcomes in terms of polymer composites strength and longevity. Further research and optimization endeavors are encouraged to enhance the use of these alternative materials in composite materials or hybrid composites manufacturing.

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