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DURABILITY CHARACTERIZATION OF CONCRETE USING PILI NUT SHELL AS AGGREGATE REPLACER

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Graphical abstract

Abstract
Pili Nuts (Canarium Ovatum), primarily found in the Province of Sorsogon in the Bicol region of the Philippines, offer a promising alternative for enhancing concrete durability while addressing sustainability and environmental concerns. The research focuses on Pili Nut Shell Powder (PNS) as a partial replacement of fine aggregate in different percentages (5%, 10%, and 15%) and evaluates the specimens at 7, 14, and 28 days. Results from durability tests, including Water Absorption (WA), Sorptivity Test (ST), and Rapid Chloride Ion Penetration Test (RCPT), underscore the positive influence of PNS on concrete properties. Notably, the 15% PNS mixture consistently outperforms, showcasing its potential to enhance concrete durability. Additional findings highlight that the 28-day water absorption of the controlled mix improved with the 15% PNS mixture, achieving a 23.3% reduction at 2.3% water absorption. In Sorptivity testing, the controlled mix displayed cumulative absorption ranging from 0.1% to 1.0% at 1 to 20 minutes. In contrast, the 15% PNS group consistently exhibited the lowest sorptivity rates, varying from 0% to 0.3% at the same intervals. For the 28-day cured specimens in the Rapid Chloride Ion Penetration Test, the controlled mix registered an average charge of 3438 coulombs. In comparison, the 15% PNS mixture proved the most effective, with the lowest average charge of 3123 coulombs, indicating enhanced resistance to chloride penetration and improved concrete durability. This research indicates an innovative approach to endorse PNS as a sustainable resource, contributing to the environmental and economic sustainability of the construction industry, with the 15% PNS mixture showing a promising result for enhancing concrete durability.

Keywords: *Pili nut shell, concrete, water absorption, sorptivity, rapid chloride ion penetration, National University, Philippines*

1.0 INTRODUCTION

The world is constantly evolving, and with that change comes the generation of waste of various kinds. A challenge in eliminating trash has emerged due to the production of non-decaying and low-biodegradable waste products and an increasing consumer population. With this, reusing waste to create valuable products is one way to address this challenge. Concrete is the most common building material, but making one uses many natural resources and materials. This harms the environment and makes the concrete industry less sustainable [1].

In the field of infrastructure development and construction, sustainable and environmentally friendly building materials are increasingly in demand [2]. Modern building is based on creating traditional concrete, which primarily relies on limited resources like sand and gravel as its fine and coarse aggregates. The role of aggregates in enhancing the durability of concrete is a critical aspect of construction materials research. Due to their various types and qualities, aggregates significantly influence the overall quality and longevity of concrete structures, occupying a substantial volume within the concrete mix. [3]. However, these resources are rapidly running out as natural resources become limited, leading to a scarcity of traditional building construction materials [4].

The qualities of some natural limestone rocks are similar to those of concrete, a man-made composite. The major components of this artificial substance are cement, fine aggregates (sand), coarse aggregates (gravels), and water [5].

In the Philippines, Pili (Canarium ovatum Engl.) dominates the global export market for pili nut products, for which it is acknowledged as a potential export commodity [6]. The Department of Agriculture recognized pili as a crop deserving of more extensive research and development efforts in recent years. Its shell is usually discarded due to its hardness and cannot be eaten [7]. Generally, the Pili nut shell is carpellary in origin, meaning it has layering, the shell is elongated and trigolous, and is nearly triangular in the transverse section, with its corners rounded and one of its sides wider than the others [8]. The shell's apical end is blunt or obtuse, while the basal end is pointed [9]. Consequently, if extracted, the shell contains 3.2% moisture, 11.9% volatile combustible matter, 11.1% ash, and 77% fixed carbon or coal [10]. The Bicol region frequently uses the shell to create various handicrafts and furniture. Numerous waste products are released into the biosphere in industrial and agricultural operations. By using these agro-industrial wastes in the creation of substitute cementitious materials like mortar and concrete, one can efficiently manage these wastes [11], [12].

The versatile Pili nut shell finds applications in various domains. It can be transformed into charcoal, a reliable fuel source [13]. Moreover, Pili nut shells were tested for their compressive strength as an aggregate in a study, and findings revealed that a standard mixture and concrete with Pili nutshells replaced as fine aggregates have high workability [14]. Therefore, this study suggests determining the durability characterization of concrete using a Pili nut shell as an aggregate replacer.

2.0 METHODOLOGY

Materials and Methods

Pili Nut Shells

Pili nut shells (PNS) were obtained directly from the province of Bicol, Philippines which is abundantly cultivated. It was removed from its pulp beforehand and dried under the heat of the sun for a couple of days before packaging it to be delivered. Upon delivery, the Pili nuts were started to be pounded into pieces first before being in a pulverizing machine, making a powdered form to be used and partially replacing fine aggregates.

Cement

Ordinary Portland Cement (OPC) was used in this study. It was kept in an airtight container and stored in a humidity-controlled room to prevent it from being exposed to moisture where the tendency of hardening is high, which must be the utmost precaution in storing the cement. \

Sand (Fine Aggregate)

The sand used in this study was retrieved from the river in Bulacan; it was washed and screened to eliminate deleterious material and oversized particles. This material is dried at room temperature for 24 hours to control the water content in the concrete. The maximum size of the fine aggregate was taken to be 4.75mm.

Gravel (Coarse Aggregate)

The gravels used in this study were bought at a hardware store in Bulacan and were meticulously chosen to fit in with the specimen size ranging from 20mm to 30mm, respectively.

Water

In this study, normal tap water available was used. It is the most essential ingredient in making concrete as it participates in the chemical reaction with the cement. It was carefully examined as it was a key material in giving strength from cement gel. The water-cement ratio used was 0.5.

Specimens

total of 108 specimens at dimensions of 4x2 inches, 27 controlled set-ups, were prepared for laboratory testing and investigation. The amount of Pili nut shell powder will be varied as 5%, 10% and 15% replacement of fine aggregates which is the Sand.

Design Mix

The design mix of the study is as follows with regards to the percentage of PNS powder in partial replacement for the fine aggregates, which is 5%, 10%, and 15%, respectively. The study used a Mixture Class of A by the distribution of 1:2:4 by Cement, Sand, and Gravel accordingly.

Table 1. Concrete Design Mix Proportion

Materials for Replacement		Cement (g)	Gravel (g)	Water (g)
Sand (g)	**Pili Nut Shell Powder**			
100%	0%	594	4950.25	297
95%	5%	594	4950.25	297
90%	10%	594	4950.25	297
85%	15%	594	4950.25	297

Design Specimens and Test Method

Water Absorption

ASTM C642-06 is a standardized test method used to determine the density, absorption, and voids in hardened concrete. Water absorption is a popular method of determining the watertightness of a concrete [15]. The water absorption test consists of two major steps: saturating the specimens followed by drying [16]. The lower the absorption, the better the result due to the higher water absorbed by the concrete, the less durable it becomes [17].

Subsequently, Water absorption of concrete plays a vital role in exhibiting the porosity within the concrete matrix. The addition of lightweight aggregates may affect the capillary suction properties due to aggregates' high water absorption properties. Besides that, the poor connectivity between aggregates due to the aggregate shape and size may also induce greater absorption characteristics due to higher voids [18].

For this test, 36 specimens of 100mm by 50mm were used. Before testing, the samples were oven-dried to achieve a constant mass at a temperature of 105°C. Secondly, they were cooled to room temperature for 24 hours. Then, the samples were immersed in a container filled with water. All the specimens were made sure to be immersed entirely underwater. They were removed from the water after 24 hours before being wiped with a cloth to achieve SSD condition. The weight of the samples was then taken, and afterward, the water absorption rate was measured using the formula below.

$$\%Water\ Absorption = \left[\frac{W_2 - W_1}{W_1}\right] x\ 10$$

Where:

W_2 = Mass of the specimen after the immersion (g)

W_1 = Mass of the oven dry specimen (g)

Sorptivity Test

It is a method where moistness transport in permeable means plays an essential role in a wide variety of processes of ecological and technological concern, such as the degradation of building materials like concrete. When excess water in concrete vaporizes, it leaves cavities inside the concrete element, creating passageways that are directly related to the concrete permeability and porousness [19].

The sorptivity can be determined by measuring the capillary rise absorption rate on reasonably homogeneous material. Water was used for the test fluid. The specimen size 100 mm x 50 mm height after drying was drowned with water level not more than 3 mm above the base of specimen, and the flow from the peripheral surface is prevented by sealing it properly with a not-absorbing coating. Afterward, the rate of cumulative absorption was measured using the formula below.

$$I = [\frac{W_2 - W_1}{Ap}]$$

Where:

I = Cumulative Absorption

W_2 = Mass of specimen at time (t)

W_1 = Mass of dried specimen (g)

A = Cross-sectional area of the surface (mm2)

p = Density of water (kg/m^3)

Table 2. Concrete Mix Design Sizes

Mix	Length (inch)	Diameter (inch)
1	2	4
2	2	4
3	2	4

Rapid Chloride Permeability Test

The Rapid Chloride Permeability Test (RCPT) evaluates the level of resistance to chloride ion penetration. Due to its simplicity and speed, the rapid chloride permeability test (RCPT-ASTM C 1202) is frequently used to assess concrete's resistance to chloride ions infiltration.

The ability of concrete to withstand chloride ion penetration is indicated electrically by the RCPT test. It makes it possible to forecast the lifespan of concrete constructions. For durability-based quality control, a concrete specimen is subjected to a constant voltage (V) for six hours. The current flowing through the concrete is measured to determine the coulombs [21].

3.0 RESULTS AND DISCUSSION

Slump Test

Table 3. Slump Test Result

Pili Nut Shell Powder Percentage to Mix Proportion	Slump (mm)	Degree of Workability
0%	162	Very High
5%	87	Medium
10%	136	High
15%	142	High

Slump test is used to determine the 'workability' of fresh concrete and has since been adapted for use in the minerals industry. The slump test finds extensive industrial applications for monitoring material consistency in tailings disposal operations. The parameter used to indicate consistency is the slump height, an empirical value that is only relevant for the specific material being tested. A study proposed that the yield stress, a unique material property, is a better measure of consistency [20].

The slump values imply that the workability of the mixture is impacted by the addition of Pili Nut Shell powder. Table 3 shows that the conventional mixture provides a 162mm slump with a very high degree of workability. In this instance, adding Pili Nut shell powder appears to lessen slump, indicating a decrease in workability. However, the degree of workability stays high even at larger percentages (10% and 15%) of Pili nut shell powder, suggesting that the combination may still be worked with easily. In comparison to the mix without Pili Nut shell powder, the concrete mix containing 15% of it has less workability and less slump. The inclusion of Pili Nut shell powder has affected the rheological qualities of the concrete, making it significantly less fluid, even though the workability is still regarded as high.

Water Absorption Test Result

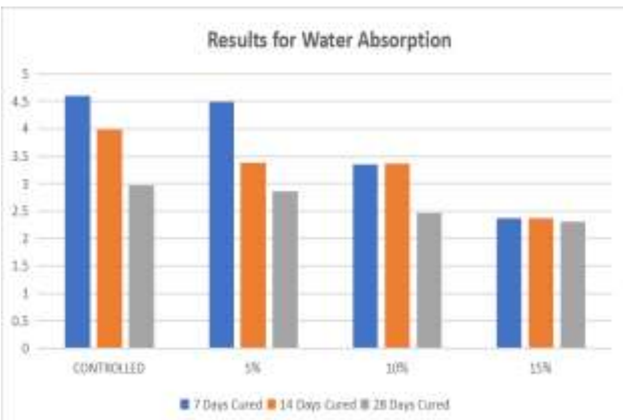

Figure 1. Summary Test Results of Water Absorption

The specimens were cured for 7, 14, and 28 days before testing them with Water Absorption. Based on Figure 1, as the mix design specimens contain a much more significant percentage of the PNS powder, their absorption rate is much lower than the conventional or controlled specimen with no PNS powder on their mix design. It depicts the influence of PNS powder on the absorption rates of concrete specimens at different curing durations. In the 7-day cured specimens, the controlled mix had a 4.59% absorption rate, while those with PNS exhibited lower rates, with 15% PNS at 2.37%, representing a 48.6% reduction. At 14 days, the controlled mix had a 3.98% absorption rate, and 15% PNS showed a 40.2% reduction at 2.36%. In 28-day cured specimens, the controlled mix registered 3.0% absorption, with 15% PNS achieving a 23.3% reduction at 2.3%. These findings underscore PNS's potential to consistently enhance concrete impermeability, especially at higher PNS percentages, indicating that a 15% PNS mixture is the most effective in reducing water absorption in concrete structures.

Statistical Treatment for Water Absorption Test

SUMMARY OUTPUT

Water Absorption	
Regression Statistics	
Multiple R	0.998613674
R Square	0.997225275
Adjusted R Square	0.996608669
Standard Error	0.06552284
Observations	12

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	13.88676978	6.943384889	1617.262	3.12341E-12
Residual	9	0.038635184	0.004293243		
Total	11	13.92540496			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	3.84064063	0.269721504	14.23929712	1.77E-07	3.230892199	4.4527871	3.230892199	4.45279706
X Variable 1	-110.2606097	1.956402887	-56.35882439	8.77E-13	-114.686358	-105.83496	-114.686336	-105.834963
X Variable 2	106.0173858	1.864410175	56.86154894	8.1E-13	101.7997063	110.23506	101.7997063	110.235065

Table 4. Statistical Treatment for Water Absorption Test

Table 4 shows the water absorption of the addition of PNS powder, which indicates a strong relationship among the variables, with a Multiple R coefficient of 0.998611674 and an R Square value of 0.99725275, indicating a strong correlation. The Adjusted R Square value of 0.996608669 and a low Standard Error of 0.06552284 further support the reliability of the results. The ANOVA results confirm the statistical significance of the relationship. With a significant level set at 0.05, the study shows that incorporating PNS powder makes the concrete specimen less susceptible to water penetration, which is a crucial factor in assessing the durability of the concrete. In practical terms, reduced water absorption suggests enhanced resistance to moisture-related deterioration, contributing to the overall durability of the concrete.

Sorptivity Test Result

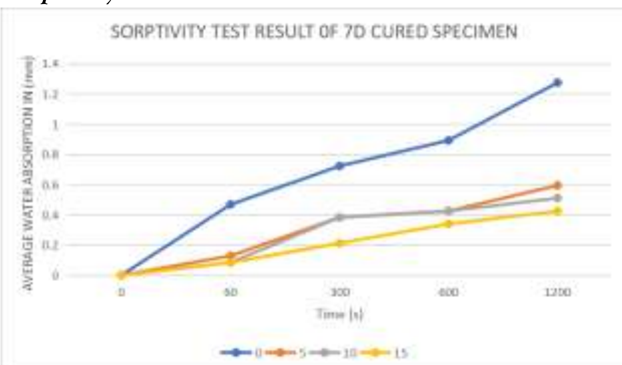

Figure 2. Sorptivity Test Results of 7D Cured Specimen

Figure 2 shows the results of the 7-day cured specimens, indicating that the sorptivity rate of concrete varies with time and the percentage of pili nut shell (PNS) content. In the control group (0% PNS), the cumulative absorption at 1 minute was 0.5%, increasing to 1.3% at 20 minutes. The sorptivity rates decreased with the addition of 5% PNS; they were 0.1% at 1 minute and progressively increased to 1.0% after 20 minutes. The sorptivity rates in the 10% PNS group also showed a similar pattern to that of the 5% PNS group. In contrast, the 15% PNS group exhibited the lowest sorptivity rates, with only 0.1% at 1 minute and a gradual increase to 0.4% at 20 minutes. These findings demonstrate that adding PNS lowers the sorptivity of concrete; throughout the 7-day curing period, the 15% PNS mixture consistently showed the highest performance in reducing water absorption.

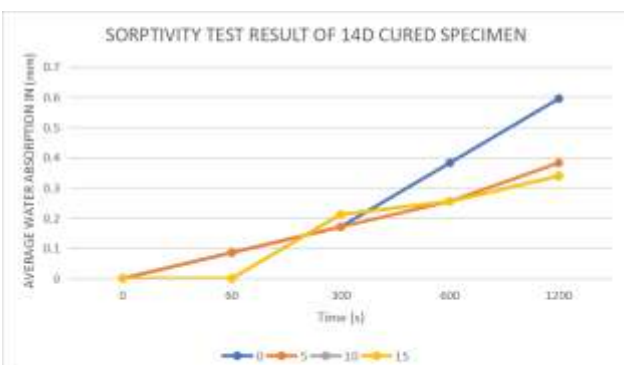

Figure 3. Sorptivity Test Results of 14D Cured Specimen

The sorptivity rates of concrete specimens with different percentages of pili nut shell (PNS) content can be determined from the findings of the specimens that were cured for 14 days. The cumulative absorption in the control group (0% PNS) varied from 0.1% at 1 minute to 1.0% at 20 minutes. The sorptivity rates decreased slightly (from 0.1% at 1 minute to 0.4% at 20 minutes) by adding 5% PNS. The sorptivity rates in the 10% PNS group also showed a slight

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decline, ranging from 0% at 1 minute to 0.3% at 20 minutes. These findings indicate that PNS generally reduces concrete's sorptivity, with the 15% PNS mixture consistently displaying the best performance in minimizing water absorption over the 14-day curing period.

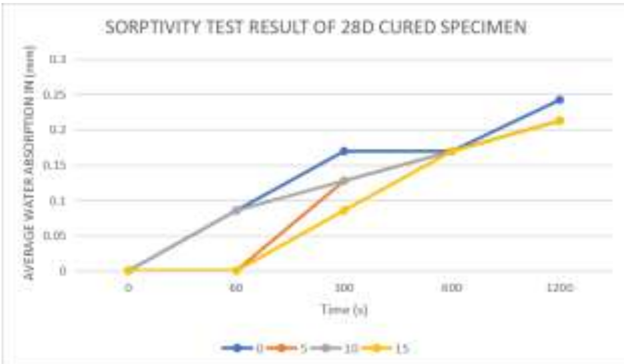

Figure 4. Sorptivity Test Results of 28D Cured Specimen

In the 28-day cured specimen, the control group (0% PNS) showed a sorptivity rate varied from 0.1 at 1 minute to 0.2% at 20 minutes. However, when adding 5% PNS, the rate decreased slightly, showing values of 0% at 1 minute and 0.2% at 20 minutes, having similar results with the 10% PNS. Notably, the 15% PNS group consistently displayed the lowest sorptivity rates, ranging from 0.1% at 1 minute to 0.2% at 20 minutes. These findings indicate that PNS generally reduces concrete's sorptivity, with the 15% PNS mixture consistently demonstrating the best performance in minimizing water absorption over the 28-day curing period.

Statistical Treatment for Sorptivity Test

SUMMARY OUTPUT

Water Sorptivity

Regression Statistics	
Multiple R	1
R Square	1
Adjusted I	0.933333333
Standard I	4.44848E-17
Observati	20

ANOVA

	df	SS	MS	F	ignificance F
Regressio	5	2.0951868	0.419037359	2.6469E+32	2.64E-223
Residual	15	2.968E-32	1.97889E-33		
Total	20	2.0951868			

	Coefficients	tandard Erro	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	-3.33067E-16	2.987E-16	-1.114898159	0.2824387	-9.698E-16	3.0369E-16	-9.698E-16	3.0369E-16
X Variable	0	0	65535	#NUM!	0	0	0	0
X Variable	-1.13283E-19	8.375E-20	-1.35267608	#NUM!	-2.918E-19	6.522E-20	-2.918E-19	6.522E-20
X Variable	3.72478E-18	3.274E-18	1.137593773	0.27313582	-3.254E-18	1.0704E-17	-3.254E-18	1.0704E-17
X Variable	4.23006E-19	3.46E-19	1.222656844	0.24032305	-3.144E-19	1.1604E-18	-3.144E-19	1.1604E-18
X Variable	0.127323954	6.14E-18	2.07355E+16	2.38E-237	0.127324	0.12732395	0.12732395	0.12732395

Table 5. Statistical Treatment for Sorptivity Test

The statistical analysis of the sorptivity test results indicates a highly significant relationship (R Square = 1) between improved resistance to water rise via sorptivity and the presence of PNS powder in concrete specimens. The adjusted R Square score of 0.93333333 shows how consistently and well it can explain changes. The accuracy and consistency of the results were depicted by the impressively low Standard Error (4.44848E-17). Moreover, this study provides strong evidence that adding PNS powder to concrete dramatically improves its durability, particularly in reducing the effects of rising capillary water. It demonstrates how PNS powder was used to increase the durability of concrete, extending the life of concrete structures.

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Rapid Chloride Ion Penetration (RCP) Test Result

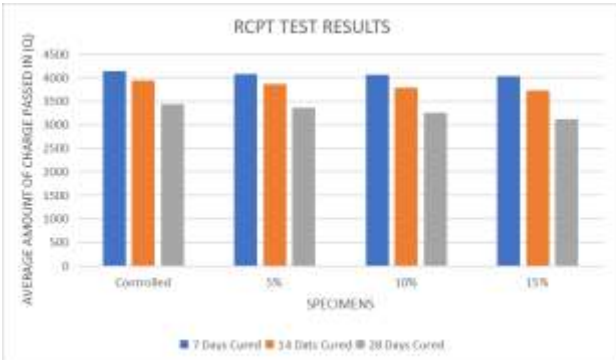

Figure 5. Summary Test Results of RCPT

In the RCPT results, the 7-day cured specimens showed that a 15% pili nut shell (PNS) mixture performed the best, with a significantly reduced average charge of 4032 coulombs, offering enhanced protection against chloride penetration and improved concrete durability. For the 14-day cured specimens, PNS percentages of 5%, 10%, and 15% all displayed comparable and enhanced resistance to chloride penetration, with an identical average charge of 3873 coulombs, making them equally effective choices for enhancing concrete durability against corrosion. In the case of the 28-day cured specimens, the 15% PNS mixture proved most effective, with the lowest average charge of 3123 coulombs, indicating enhanced resistance to chloride penetration and improved concrete durability. Overall, the 15% PNS mixture consistently performed the best in reducing the potential for affecting concrete's durability against corrosion across all curing durations.

Statistical Treatment for Rapid Chloride Penetration Test

SUMMARY OUTPUT	
Regression Statistics	
Multiple R	1
R Square	1
Adjusted R Square	65535
Standard Error	0
Observations	3

Anova: Single Factor						
SUMMARY						
Groups	Count	Sum	Average	Variance		
Column 1	9	0.14	0.015555556	2.7778E-05		
Column 2	9	0.19	0.021111111	1.1111E-05		
Column 3	9	0.43	0.047777778	1.9444E-05		
Column 4	9	0.6	0.066666667	0.000025		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	1.150275254	12	0.095856268	1442.46731	9.3E-110	1.8464258
Within Groups	0.006911111	104	6.6453E-05			
Total	1.157186325	116				
2254.545455	2254.545455					
2177.272727	2177.272727					
1440.909091	1440.909091					
-600	-600					
5359.090909	5359.090909					

Table 6. Statistical Treatment for Rapid Chloride Penetration Test

Although the Rapid Chloride Penetration test statistical treatment findings show remarkable correlation values, Table 6 concern should be taken to account for the relatively small sample size as well as potential overfitting. However, the perfect correlation points to a substantial connection between enhanced resistance to rapid chloride ion penetration and PNS powder presence. This suggests that the presence of PNS powder may serve as an effective protective measure against chloride-induced corrosion, a common durability concern in concrete structures.

4.0 CONCLUSION

The results of this study demonstrate the importance of using Pili nutshell powder as a partial replacement for fine aggregate in concrete and its impact on durability across a range of examined parameters. According to the research, the powder amount percentage of Pili nut shell replacement significantly impacts the durability and quality of concrete. The slump test result demonstrates that the controlled mix (0% PNS Powder) has an excellent workability of 162mm slump. The slump lessens with the addition of Pili Nut shell powder, suggesting a decrease in workability. Despite this, the degree of workability stays high, even with increasing percentages (10% and 15%) of PNS powder indicating high workability.

Throughout the test, the 15% PNS mixture consistently demonstrates superior performance, highlighting its potential to enhance concrete durability significantly. Additional observations reveal that after 28 days, the controlled mixture exhibits a water absorption rate of 3.0%, while the 15% PNS mixture achieves a noteworthy 23.3% reduction, registering 2.3% water absorption. In Sorptivity testing, the controlled mixture depicts cumulative absorption levels ranging from 0.1% to 1.0% over 1 to 20 minutes. Conversely, the 15% PNS group consistently displays the lowest sorptivity rates, varying from 0% to 0.3% during the same intervals. For the 28-day cured specimens in the Rapid Chloride Ion Penetration Test, the controlled mixture records an average charge of 3438 coulombs. The 15% PNS mixture proves highly effective, with the lowest average charge of 3123 coulombs. It underscores superior resistance to chloride penetration and an overall enhancement in concrete durability.

Among all the tests conducted, such as Water Absorption, Sorptivity, and Rapid Chloride Penetration Test (RCPT), a clear pattern emerged, demonstrating a favorable relationship between the increasing percentage of PNS powder in the mix design and the resulting positive impacts. The 15% PNS mixture consistently exhibited the lowest absorption rates across all curing durations, indicating its effectiveness in enhancing concrete impermeability. Regarding the Sorptivity test, the 15% PNS mixture is the most effective in minimizing water absorption over the 7-day and 14-day curing periods. As for the RCPT, the 15% PNS mixture consistently performed best in enhancing resistance to chloride penetration. This research introduces an innovative perspective by endorsing PNS as a sustainable resource, contributing to the environmental and economic sustainability of the construction industry. The 15% PNS mixture is promising for reinforcing concrete durability, showcasing its potential in formal research applications.

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