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Sustainable Concrete with Bethamcherla Waste Stone and Polyvinyl-Alcohol: Mechanical Properties and NDT Evaluation

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Abstract
Concrete is the most widely used construction material globally, valued for its strength, durability, and versatility. With the increasing demand for sustainable construction practices, the search for alternative materials that maintain performance while conserving resources has become essential. This study explores the development of M20 and M50 grade concrete using partial replacement of conventional coarse aggregates with Bethamcherla stone at varying levels of 10%, 20%, 30%, 40%, and 50% by weight. Bethamcherla stone, known for its distinct physical characteristics, is investigated for its potential to enhance resource efficiency in concrete production. Additionally, a self-curing agent, Polyvinyl Alcohol (PVA), is incorporated at dosages of 0.03%, 0.06%, 0.12%, and 0.24% by weight of cement. PVA aids in internal moisture retention, reducing the need for external water curing particularly beneficial in water-scarce regions. The performance of the modified concrete is evaluated through tests on fresh properties such as workability and slump, as well as hardened properties like compressive strength using rebound hammer and ultrasonic pulse velocity tests conducted at 7, 14, and 28 days. The findings aim to support the development of environmentally conscious concrete that meets structural and performance standards while addressing resource and water management challenges.

1. Introduction

Concrete remains one of the most widely used materials in the construction industry due to its strength, versatility, and durability. Its composition typically includes cement, fine and coarse aggregates, and water. However, with the rapid pace of urban development and infrastructure expansion, the demand for natural construction materials has increased significantly, leading to resource depletion and environmental concerns. This situation has prompted researchers and engineers to explore more sustainable alternatives that can reduce environmental impact while maintaining the performance standards of conventional concrete. In this context, the use of locally available and less commonly used materials has gained traction. Bethamcherla stone, a type of dense limestone found in specific regions, presents itself as a promising substitute for natural coarse aggregates.

At the same time, water scarcity in many parts of the world has highlighted the need for alternative curing methods. Incorporating self-curing agents like Polyvinyl Alcohol (PVA) into concrete mixes offers a potential solution by enabling internal moisture retention and reducing reliance on external water curing. This study investigates the effects of replacing coarse aggregates with varying proportions of Bethamcherla stone and incorporating different dosages of PVA in M20 and M50 grade concrete. The goal is to evaluate how these modifications influence the fresh and hardened properties of concrete while contributing to sustainable construction practices [1].

2. Research Background

Concrete is a foundational material in construction, valued for its strength, durability, and adaptability. However, growing concerns about environmental sustainability and the depletion of natural aggregates have led to the exploration of alternative materials. One such alternative is Bethamcherla stone, a dense, locally sourced limestone that shows promise as a partial substitute for traditional coarse aggregates. Research suggests that its physical characteristics, such as angularity and strength, can improve the bond with the cement matrix and enhance the overall performance of concrete. Additionally, using regionally available stones like Bethamcherla may reduce the environmental impact associated with the transportation of raw materials. At the same time, internal curing methods are gaining attention for their role in promoting efficient hydration in concrete. Polyvinyl Alcohol (PVA), a hydrophilic polymer, has been found effective in retaining moisture within the concrete matrix, reducing dependency on external water curing. This is especially beneficial in areas with limited water availability, as it can support the curing process and reduce shrinkage-related issues. Different grades of concrete, such as M20 and M50, react differently to changes in mix composition. High-strength concrete like M50, in particular, demands precise mix design to maintain both workability and performance. To evaluate the effects of incorporating alternative materials and self-curing agents, standardized tests such as the slump test, rebound hammer test, and ultrasonic pulse velocity (UPV) are commonly employed. These tests help in assessing both fresh and hardened properties of concrete. Furthermore, the use of alternative aggregates and self-curing agents aligns with broader sustainability goals in construction. By promoting the use of locally sourced materials and reducing water usage, these innovations contribute to more eco-friendly building practices. While promising, ongoing research is essential to determine the ideal proportions and combinations of these materials for various structural applications [2].

2.1. Objectives of the Study

- To investigate the feasibility of using Bethamcherla stone as a partial replacement for conventional coarse aggregates in M20 and M50 grade concrete at varying proportions (10%, 20%, 30%, 40%, and 50% by weight).
- To evaluate the effect of incorporating Polyvinyl Alcohol (PVA) as a self-curing agent at different dosages (0.03%, 0.06%, 0.12%, and 0.24% by weight of cement) on the hydration and curing performance of concrete.
- To analyze the fresh properties of the modified concrete mixtures, particularly workability and slump, to ensure suitability for practical applications.
- To assess the hardened properties of concrete, including compressive strength development at 7, 14, and 28 days, using rebound hammer and ultrasonic pulse velocity (UPV) tests.
- To determine the optimal combination of Bethamcherla stone and PVA dosage that provides a balance between sustainability, strength, and durability without compromising structural integrity.
- To promote the use of locally available alternative materials and internal curing methods to reduce reliance on natural aggregates and external water curing, thereby supporting eco-friendly construction practices.
- To contribute to the body of knowledge on sustainable concrete technologies, offering practical recommendations for water-efficient and resource-conscious construction in water-scarce and resource-limited regions [3].

3. Experimental Work

3.1. Materials Used

Cement: The cement employed in this research was 53-grade Ordinary Portland Cement (OPC), chosen for its suitability in high-strength concrete mixes. It had a specific gravity of 3.14. As per the testing standards outlined in IS 8112:1989, the cement demonstrated a fineness of 282 m²/kg, a standard consistency of 32%, an initial setting time of 35 minutes, and a final setting time of 555 minutes. These characteristics confirm its adequacy for structural applications requiring enhanced performance.

Fine Aggregate: Well-graded fine aggregate passing through a 4.75 mm sieve was selected for the study. The sand used had a specific gravity of 2.55 and a fineness modulus of 4.75. Its bulk density was recorded at 16.42 kN/m³. Additionally, the sand exhibited a bulking value of 24.63% and fell under Zone-II classification, indicating its quality and suitability for use in concrete production [4].

Coarse Aggregate: The coarse aggregate utilized consisted of naturally available crushed stones with a maximum size of 20 mm, locally procured. Testing was carried out in accordance with IS: 2386 (Part III)-1963. The aggregates had a specific gravity of 2.86 and a fineness modulus of 3.50. Other observed properties included a flakiness index of 17.45%, an elongation index of 24.60%, a crushing value of 18.56%, an impact value of 16.75%, and water absorption rate of 0.50%, all of which fall within acceptable limits for structural-grade concrete Shown in Table 1.

Table 1 Physicochemical Properties of Polyethylene Oxide (PEO)

Property	Value and Description
Chemical Formula	$(C_2H_4O)n$
Appearance	White to off-white powder and granular in shape
Solubility in Water	Highly soluble
Melting Point	230°C
Density	1.29 g/cm³
pH (1% solution)	5.62

Bethamcherla Waste Stone Aggregate: The Bethamcherla stone waste used in this study originated from tile manufacturing units, where large quantities of stone waste are generated during the cutting and shaping of flooring tiles. Due to its irregular size, the raw waste cannot be directly incorporated into concrete mixtures. To make it usable, the material is transported to crushing facilities where it is processed into appropriately sized graded aggregates, making it suitable for concrete applications and promoting waste reutilization Shown in Table 2.

Table 2 Properties of Bethamcherla stone

Physical Property	Value and Description
Color	Varies – mostly beige, cream, white, or grey
Texture	Fine-grained.
Density	2.64 g/cm³
Specific Gravity	2.75
Porosity	Low; compact and impervious
Water Absorption	0.75 % (< 1%)
Compressive Strength	93 N/mm²
Durability	High – resistant to weathering and erosion
Workability	Good – easily cut and polished
Thermal Resistance	Stable up to 400°C; deteriorates above 600°C

Polyvinyl –Alcohol (PVA): In this study, polyvinyl alcohol (PVA) is used as a self-curing agent at varying concentrations of 0.03%, 0.06%, and 0.12% by weight. PVA is recognized for its strong water-retention capability, which helps minimize moisture loss during the curing phase. When added to the concrete mix, it promotes better hydration and contributes to improved compressive strength. The primary goal of incorporating PVA is to enhance water management during curing and support more effective and sustainable curing techniques [5].

4. Mix Proportions

In this experimental investigation, concrete mixes were proportioned to achieve characteristic compressive strengths corresponding to M20 and M50 grades, as per the guidelines prescribed in IS 10262:2009. The mix design incorporated conventional materials, including river sand as fine aggregate and crushed granite as coarse aggregate.

However, in a novel approach to partially replace traditional coarse aggregate, Bethamcherla stone was utilized. The substitution was carried out in incremental proportions of 0%, 10%, 20%, 30%, 40%, and 50% by weight of cement. In addition to aggregate modification, the study explored the self-curing potential of Polyvinyl Alcohol (PVA). PVA was added to the concrete mixes at dosages of 0.03%, 0.06%, 0.12%, and 0.24% of the cement content. This additive was intended to enhance internal curing and minimize water loss, thereby improving the hydration process, particularly in high-performance concrete. For each mix configuration, a total of six concrete cubes and six cylindrical specimens were prepared to facilitate comprehensive testing. These specimens underwent mechanical property evaluations—specifically, compressive strength for cubes and split tensile strength for cylinders—at three distinct curing intervals: 7 days, 14 days, and 28 days. This systematic assessment allowed for a detailed understanding of the influence of both Bethamcherla stone and PVA on the strength development and durability characteristics of concrete over time [6].

5. Casting of Specimens

Prior to casting, all cube and cylinder moulds were meticulously cleaned to eliminate any residual debris, dust, or hardened concrete that could interfere with the quality and uniformity of the new specimens. This step ensured a clean surface for the fresh concrete to be placed, promoting consistency in test results. To prevent the concrete from sticking to the mould surfaces and to eliminate any potential for leakage during the casting process, a uniform and thin layer of form-release agent (commonly referred to as mould oil) was carefully applied to the inner faces of each mould. This application also facilitated the smooth removal of the hardened specimens after curing without causing surface damage or deformation. Once the moulds were adequately prepared, freshly mixed concrete was placed into each mould in layers. The concrete was compacted in three successive layers using a standard tamping rod. Each layer was thoroughly tamped to eliminate entrapped air and ensure proper compaction, which is essential for achieving the desired strength and durability of the specimens. This methodical approach was followed consistently for both cube and cylindrical specimens to maintain uniformity throughout the study [7].

6. Self-Curing in Concrete

Self-curing represents a modern advancement in concrete technology, aimed at enhancing the hydration of cement without the dependency on traditional external water-curing practices. In this technique, special chemical compounds known as self-curing agents are incorporated into the concrete mix. These agents function by retaining water within the concrete structure, ensuring a sustained supply of moisture necessary for the cement hydration process. This approach proves especially advantageous in areas facing water scarcity or in large-scale construction projects where maintaining continuous external curing is logistically difficult or inefficient. In the present study, Polyvinyl Alcohol (PVA), a synthetic water-soluble polymer, was utilized as a self-curing additive. PVA was introduced into the concrete in varying dosages of 0.03%, 0.06%, 0.12%, and 0.24% by weight of cement. Its primary role is to reduce internal moisture loss by forming a film or network that retains water within the cementitious matrix. This internal moisture conservation supports ongoing hydration over time, which is critical for the development of strength and durability in concrete. By incorporating PVA into the mix, the need for continuous water curing from external sources is significantly reduced. This not only contributes to water conservation but also ensures more uniform curing, particularly in inaccessible or complex structural elements. Furthermore, self-curing helps mitigate issues such as shrinkage, surface cracking, and early-age defects that often result from inadequate curing. Overall, the use of PVA as a self-curing agent enhances the concrete’s performance by maintaining consistent internal moisture conditions, thus facilitating optimal strength gain and long-term structural integrity [8].

7. Testing Methods

7.1. Workability Test

To evaluate the ease of handling and consistency of freshly mixed concrete, the Slump Test was employed—a widely accepted method for assessing workability. This test provides insights into the concrete's ability to be mixed, placed, and compacted efficiently without experiencing issues such as segregation or excessive bleeding. The procedure involves filling a standard slump cone (a frustum-shaped mold) with fresh concrete in three layers, each compacted uniformly. Once the mold is completely filled, it is carefully lifted vertically, allowing the concrete to subside or "slump" due to its own weight. The degree of vertical settlement is then measured by calculating the difference between the original height of the mold and the highest point of the slumped concrete. This measured slump value reflects the workability of the concrete mix. A higher slump indicates greater fluidity and ease of placement, while a lower slump suggests a stiffer, less workable mix. The results of this test help determine whether the concrete possesses suitable consistency for the intended construction application [9].

7.2. Rebound Hammer Test

The Rebound Hammer Test, commonly referred to as the Schmidt Hammer Test, is a non-destructive testing method used to evaluate the surface hardness of concrete and provide an approximate indication of its compressive strength. This technique is particularly useful for assessing in-place concrete without causing damage to the structure. In the context of this study, the Rebound Hammer Test was employed to monitor the development of strength in self-curing concrete mixtures. Various proportions of Polyvinyl Alcohol (PVA) were incorporated into the concrete at replacement levels of 0.03%, 0.06%, 0.12%, and 0.24% by weight of cement. The test was conducted to observe how the inclusion of PVA influenced surface hardness and to estimate corresponding improvements in compressive strength over time.

7.3. Ultrasonic Pulse Velocity (UPV) Test

The Ultrasonic Pulse Velocity Test is a widely used non-destructive testing method employed to evaluate the quality and uniformity of concrete. It measures the velocity of ultrasonic pulses passing through the concrete, which helps in determining its density, homogeneity, and indirectly, its compressive strength. Higher pulse velocities generally indicate better quality concrete with fewer internal flaws or voids. In this study, the UPV test was used to assess the internal quality and strength development of self-curing concrete mixes incorporating Polyvinyl Alcohol (PVA) as a curing agent. PVA was added at different dosage levels—0.03%, 0.06%, 0.12%, and 0.24% by weight of cement. The objective was to observe how the presence of PVA influenced the internal structure and integrity of the concrete over time. The results from the UPV test provided valuable insights into the effectiveness of self-curing in maintaining concrete quality and enhancing strength without relying on traditional external curing methods [10].

8. Test Result and Discussions

8.1. Fresh Properties of Concrete

The workability of the concrete mixes was assessed using the slump cone test, a standard method for evaluating the ease of handling and placement of fresh concrete. It was observed that the workability decreased progressively with the partial replacement of conventional coarse aggregate by Bethamcherla stone Shown in Table 3. Additionally, the incorporation of Polyvinyl Alcohol (PVA) as a self-curing agent further contributed to the reduction in slump values. This decline in workability can be attributed to the angular texture of Bethamcherla stone and the water-retaining nature of PVA. The slump test results corresponding to different levels of aggregate replacement and PVA dosage are presented in the graph below Shown in Figure 1.

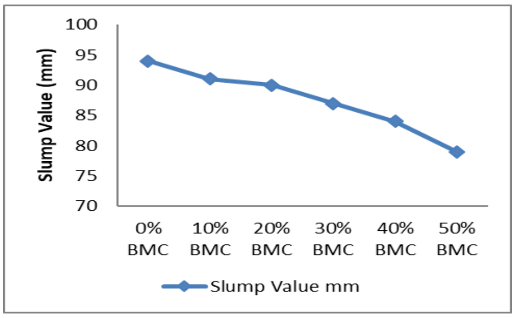

Figure 1 Slump with different mixed proportions of BMC and PVA

Table 3 Slump Test Results

% of BMC Stone	Slump Value mm	Workability
0% BMC	94	Medium
10% BMC	91	Medium
20% BMC	90	Medium
30% BMC	87	Medium
40% BMC	84	Medium
50% BMC	79	Medium

As the proportion of Bethamcherla stone rises, the slump values show a little decrease. Compared to traditional coarse aggregates, Bethamcherla stone has a higher propensity to absorb water, which explains this drop in workability. Slump values decrease as the percentage of Bethamcherla stone increases because it absorbs more water from the mixture, diminishing the amount of free water available. On the other hand, the initial slump values are barely affected when Polyvinyl Alcohol (PVA) is used as a self-curing agent. This is due to the fact that PVA needs a longer reaction time in order to affect the curing process by holding onto moisture in the mixture. Although it helps with hydration and moisture retention, its effects become increasingly noticeable over time [11 - 13].

8.2. Hardened Concrete Properties

In order to evaluate and verify the quality of cement concrete work, testing hardened concrete is essential. The test procedures must to be clear, precise, and simple to use Shown in Table 4 - 7.

8.2.1. Rebound Hammer

In general, a higher rebound number denotes stronger concrete and possibly better compressive strength, while a lower number indicates weaker concrete. The hammer's rebound number is taken straight off a scale, and empirical calibration curves supplied by the manufacturer or as specified by applicable standards are used to connect it to compressive strength Shown in Figure 2 - 19.

Table 4 Rebound Hammer and its calibrated Compressive Strength of M20 Concrete

	% PVA	7 Days		14 Days		28 Days	
		Avg Rebound Number	Compressive Strength	Avg Rebound Number	Compressive Strength	Avg Rebound Number	Compressive Strength
10% BWS	0.03%	13	15	15	17	18	21
	0.06%	14	16	15	17	19	22
	0.12%	15	17	17	20	21	25
	0.24%	14	16	16	19	18	21
20% BWS	0.03%	14	16	15	17	19	22
	0.06%	15	17	16	19	19	22
	0.12%	16	19	18	21	22	26
	0.24%	14	16	17	20	20	24
30% BWS	0.03%	15	17	17	20	20	24
	0.06%	16	19	18	21	22	26
	0.12%	17	20	20	24	24	28
	0.24%	15	17	19	22	21	25
40% BWS	0.03%	14	16	16	19	18	21
	0.06%	14	16	16	19	19	22
	0.12%	16	19	19	21	21	26
	0.24%	15	17	17	20	19	25
50% BWS	0.03%	13	15	15	18	18	21
	0.06%	14	16	16	19	19	22
	0.12%	15	17	17	20	21	25
	0.24%	13	15	14	16	19	22

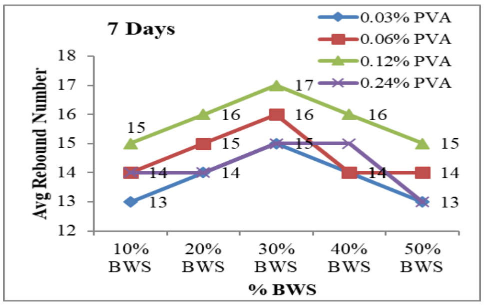

Figure 2 Avg Rebound Number with respect to % BWS at 7 Days of Curing for M20 grade of concrete

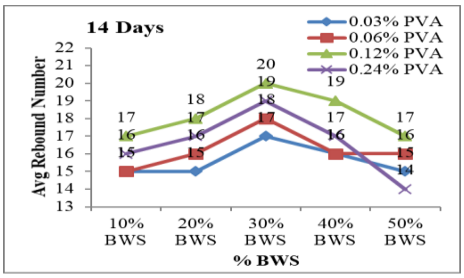

Figure 3 Avg Rebound Number with respect to % WS at 14 days of curing for M20 grade of concrete

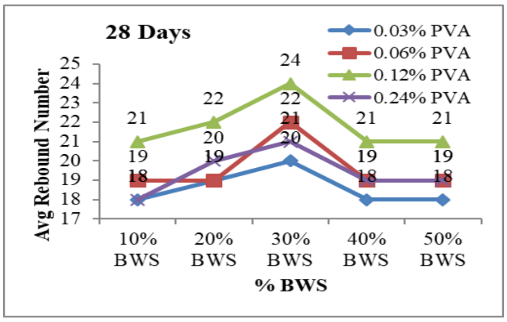

Figure 4 Avg Rebound Number with respect to % WS at 28 days of curing for M20 grade of concrete

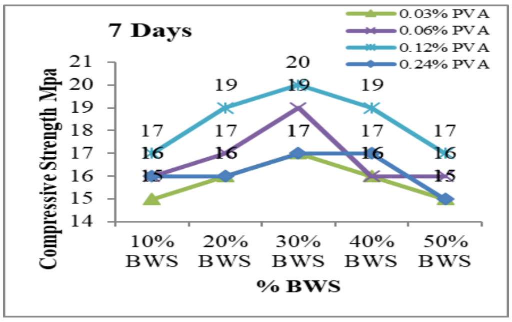

Figure 5 Compressive Strength with respect to % WS at 7 days of curing for M20 grade of concrete

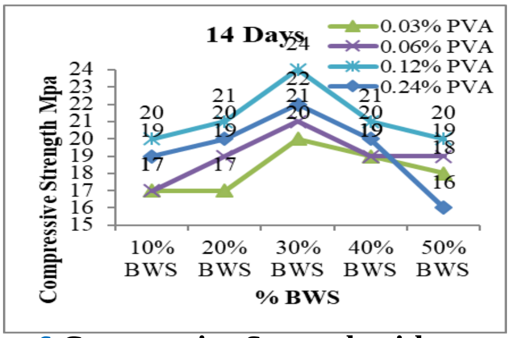

Figure 6 Compressive Strength with respect to % WS at 14 days of curing for M20 grade of concrete

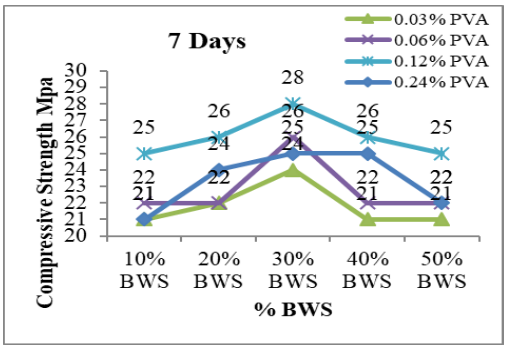

Figure 7 Compressive Strength with respect to % BWS at 28 days of curing for M20 grade of concrete

Table 5 Rebound Hammer and its alibrated Compressive Strength of M50 Concrete

	Percentage PVA	7 Days		14 Days		28 Days	
		Avg Rebound Number	Compressive Strength	Avg Rebound Number	Compressive Strength	Avg Rebound Number	Compressive Strength
10% BWS	0.03 %	37	39	42	46	53	57
	0.06 %	38	41	42	46	53	57
	0.12 %	40	43	45	49	54	58
	0.24 %	38	41	44	48	53	57
20% BWS	0.03 %	38	41	43	47	54	58
	0.06 %	40	43	45	49	54	58
	0.12 %	41	44	45	49	56	60
	0.24 %	38	41	44	48	55	59
30% BWS	0.03 %	40	43	43	47	54	58
	0.06 %	41	44	44	48	55	59
	0.12 %	42	46	47	51	58	62
	0.24 %	40	43	46	50	56	60
40% BWS	0.03 %	39	42	45	49	55	59
	0.06 %	38	41	46	50	56	60
	0.12 %	41	44	47	51	56	60
	0.24 %	40	43	46	50	55	59
50% BW	0.03 %	37	40	42	46	53	57
	0.06 %	37	40	44	48	54	58
	0.12	40	43	46	50	56	60

S	%						
	0.24 %	37	40	43	47	54	58

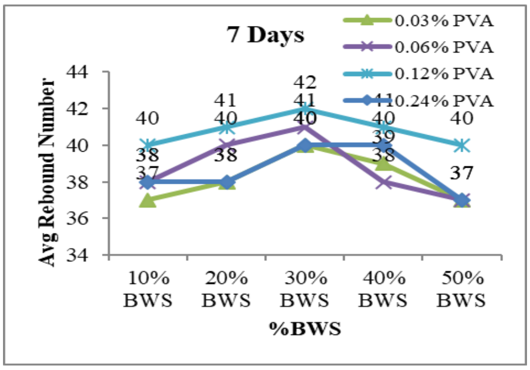

Figure 8 Avg Rebound Number with respect to % WS at 7 days of curing for M50 grade of concrete

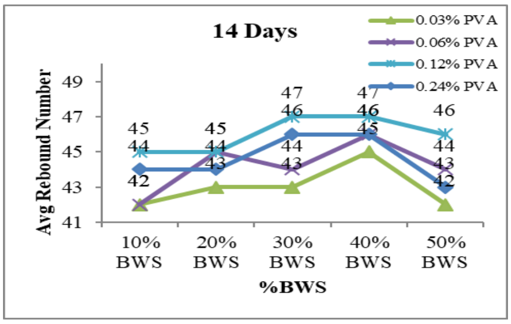

Figure 9 Avg Rebound Number with respect to % WS at 14 days of curing for M50 grade of concrete

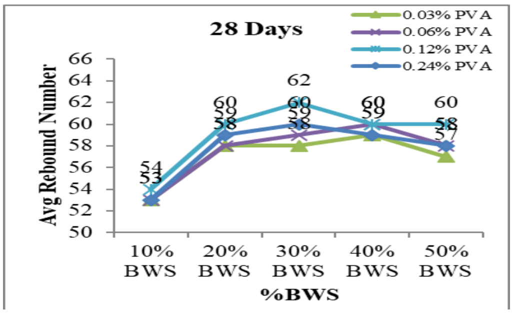

Figure 10 Avg Rebound Number with respect to % WS at 28 days of curing for M50 grade of concrete

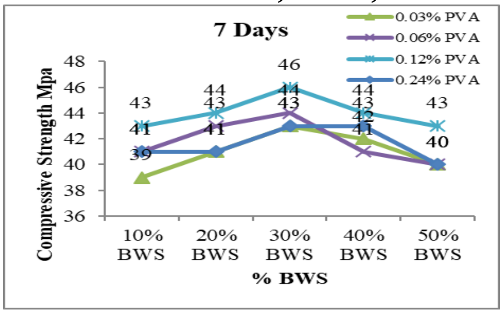

Figure 11 Compressive Strength with respect to % WS at 7 days of curing for M50 grade of concrete

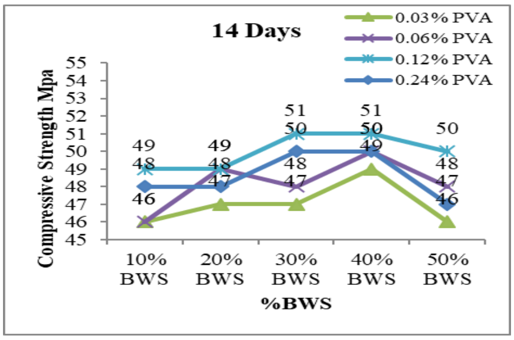

Figure 12 Compressive Strength with respect to % WS at 14 days of curing for M50 grade of concrete

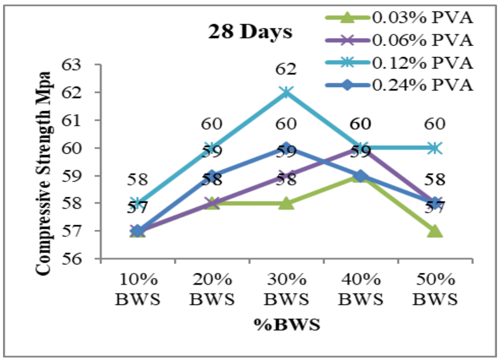

Figure 13 Compressive Strength with respect to % BWS at 28 days of curing for M50 grade of concrete

8.3. Ultrasonic Pulse Velocity

Table 6 Ultrasonic Pulse Velocity- M20

		7 Days	14 Days	28 Days
		Ultrasonic pulse velocity(m/s)	Ultrasonic pulse velocity (m/s)	Ultrasonic pulse velocity (m/s)
0.03% PVA	10%	4747	4854	4702
	20%	4702	4702	4732
	30%	4601	4702	4902

	40%	4747	4886	4902
	50%	4658	4732	4902
0.06% PVA	10%	4747	4904	4902
	20%	4559	4601	4335
	30%	4886	4823	4926
	40%	4854	4854	4924
	50%	4601	4777	4823
0.12% PVA	10%	4702	4712	4777
	20%	4559	4601	4630
	30%	4287	4335	4947
	40%	4399	4747	4630
	50%	4176	4237	4702
0.24% PVA	10%	4237	4425	4601
	20%	4267	4607	4771
	30%	4399	4656	4752
	40%	4178	4202	4630
	50%	4202	4300	4808
Conventional				5017

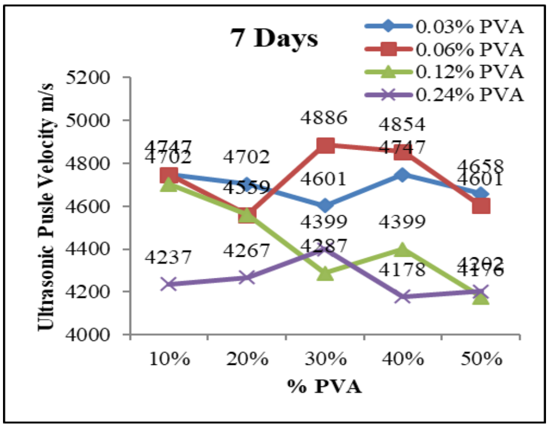

Figure 14 Ultrasonic Pulse Velocity with respect to % PVA at 7 days of curing for M20 grade of concrete

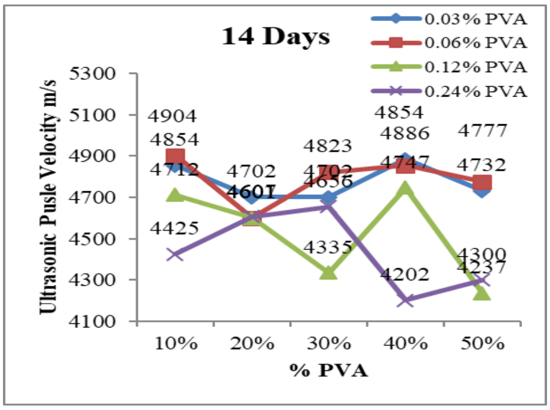

Figure 15 Ultrasonic Pulse Velocity with respect to % PVA at 14 days of curing for M20 grade of concrete

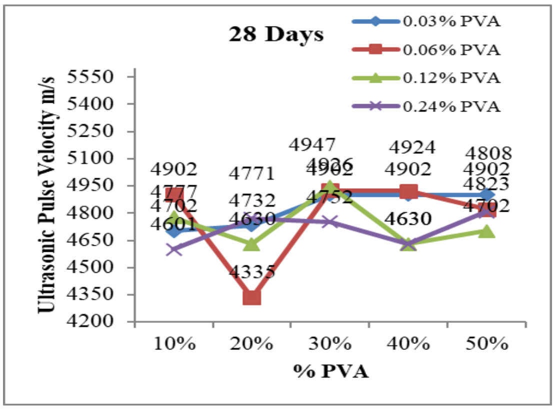

Figure 16 Ultrasonic Pulse Velocity with respect to % PVA at 28 days of curing for M20 grade of concrete

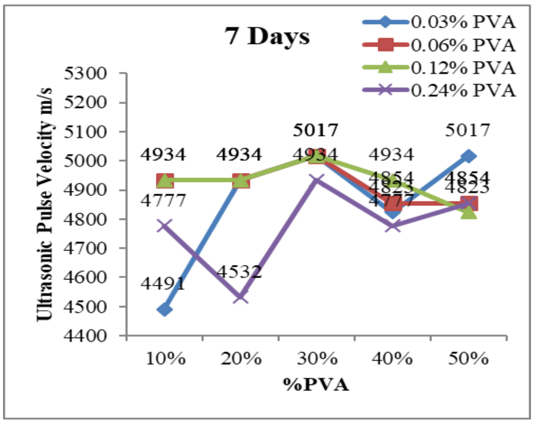

Figure 17 Ultrasonic Pulse Velocity with respect to % PVA at 7 days of curing for M50 grade of concrete

Table 7 Ultrasonic Pulse Velocity- M50

		7 Days	14 Days	28 Days
		Ultrasonic pulse velocity (m/s)	**Ultrasonic pulse velocity (m/s)**	**Ultrasonic pulse velocity (m/s)**
0.03 % PVA	10%	4491	4491	4491
	20%	4934	4934	4934
	30%	5017	5068	5068
	40%	4823	4886	4934
	50%	5017	5017	5068
0.06 % PVA	10%	4934	5017	5017
	20%	4934	4934	4934
	30%	5017	5017	5017
	40%	4854	4967	5017
	50%	4854	4886	5137
0.12 % PVA	10%	4934	5017	5068
	20%	4934	4934	5102
	30%	5017	5017	5117
	40%	4934	4934	5017
	50%	4823	4854	4854
0.24 % PVA	10%	4777	4777	4886
	20%	4532	4630	4673
	30%	4934	4934	4934
	40%	4777	4777	4922
	50%	4854	4854	4902
Conventional				5017

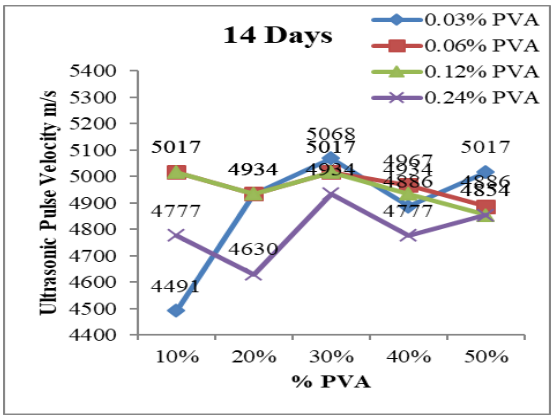

Figure 18 Ultrasonic Pulse Velocity with respect to % PVA at 14 days of curing for M50 grade of concrete

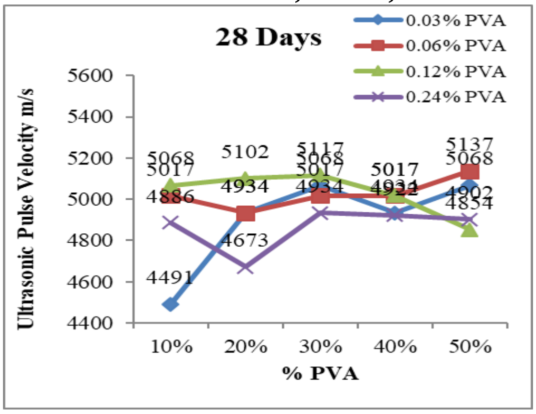

Figure 19 Ultrasonic Pulse Velocity with respect to % PVA at 28 days of curing for M50 grade of concrete

Conclusion

This study examined the impact of using Bethamcherla aggregates in place of certain coarse aggregate and cement weight combined with silica fume and poly-vinyl alcohol. The best mixture for crushing & split tensile strengths was found to be 30%BMC+0.12%PVA, according to early studies. A workability test was performed on each mixture. For each blend, mechanical properties including splitting tensile strength and cube compressive strength were measured. The experimental inquiry produced the following conclusions.

- The slump, which indicates the concrete's workability, diminishes with increasing BMC and PVA replacement. The and the results fall into the usual concrete range.
- The specific gravity of the PVA that were obtained is lower than that of the Office of Pest Control and coarse aggregate that they replaced. It implies that a substantially larger volume of cementitious substances will be produced by mass replacement.
- Compressive strength increased up to 30% and 0.12% with BMC and PVA substitution, respectively, and then stopped at the remaining ratios. In comparison to the concrete's goal strength, the compressive strength increased by about 18.08% and 24.15% on the 7th and 28th day, respectively.
- With BMC & PVA substitution, the cylinder's cracking tensile strength peaked at 30% and 0.12%, respectively, and then decreased at all ages. There was around a tensile strength improvement in splitting

compared to goal strength. 18.11% and 24% at 7th and 28th day respectively.

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