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Understanding the Long-Term Development of Portland Pozzolan Cement Concrete Post 28 Days †

Muhammad Faisal *, Jessica Sjah and Josia Irwan Rastandi

Department of Civil Engineering, Faculty of Engineering, Universitas Indonesia, Depok 16424, Indonesia; jessicasjah@eng.ui.ac.id (J.S.); jrastandi@eng.ui.ac.id (J.I.R.)

* Correspondence: muhfsl@gmail.com

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Abstract: This study examines the age-dependent development of compressive strength in Portland pozzolan cement (PPC) concrete under both curing and non-curing conditions. Four beam specimens, each measuring 500 mm × 200 mm × 350 mm, were prepared with varying compressive strengths. Testing was conducted at 28, 60, 90, and 180 days using the rebound hammer test and Windsor Pin Test. The results indicate the tool's reliability in predicting gradual increases in strength over time. However, this correlation suggests that the factors influencing compressive strength, such as moisture, concrete age, surface smoothness, and environmental exposure, play crucial roles in affecting rebound readings and surface hardness.

Keywords: Portland Pozzolan Cement; compressive strength; rebound hammer; Windsor Pin Test

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1. Introduction

The post-28-day strength of Portland composite cement concrete is a crucial factor in evaluating its durability and long-term performance. Portland composite cement concrete has lower early compressive strength than ordinary Portland cement concrete. This situation occurs because pozzolans interact with calcium hydroxide, which is produced during the hydration of Portland cement, resulting in the formation of a secondary cementitious material that enhances long-term strength. The relatively low early-age strength of PPC poses a challenge in the construction industry, as achieving sufficient strength early in the process is crucial for enabling faster and more effective construction practices [1].

One of the commonly used methods to assess the strength of Portland composite cement concrete is the Windsor Pin Test. This test involves the use of a Windsor probe system to measure the in situ strength, C, of concrete. By driving a probe into the concrete and measuring the depth of penetration, this test provides valuable insights into the concrete's strength and quality [2].

In addition to the Windsor Pin Test, the hammer test uses a rebound hammer to evaluate concrete strength by measuring the rebound from the surface, providing a reliable indication of strength and durability [3].

Recent investigations have explored the compressive strength of PPC concrete relative to OPC concrete. The compressive strength of foam concrete made with Portland composite cement at early ages—specifically on day 7—was found to be lower compared to that of foam concrete made with ordinary Portland cement [4]. Kencanawati et al. conducted a study comparing the compressive strength of concrete between Portland pozzolan cement (PPC) and Plain Cement Concrete (P.C.C.). Their research revealed that PPC concrete typically undergoes a gradual increase in strength from 7 to 42 days of testing. Despite its slower reactivity initially, PPC concrete eventually achieves superior strength at later ages [5].

While multiple studies have shown that assessing concrete strength development using non-destructive test equipment [6,7] is feasible, research specifically investigating this development in PPC concrete remains limited. This research will employ a multi-pronged approach to investigate the concrete strength of PPC concrete using concrete beam specimens. Testing will be performed at 28, 60, 90, and 180 days. The results of this research will provide valuable insights into the long-term performance and durability of PPC concrete, allowing for more accurate predictions of its strength and suitability for various construction applications.

2. Materials and Methods

2.1. Materials

In this research, concrete samples were prepared utilizing instant concrete sourced from the DynaMix PakCrete product series. To ensure a diverse range of strengths, seven distinct mix groups were formulated, each targeting specific compressive strengths as indicated by the product specifications: 14.25 MPa, 16.28 MPa, 18.32 MPa, 20.36 MPa, 22.39 MPa, 24.43 MPa, and 28.50 MPa. The coarse aggregate comprised crushed stone with a maximum diameter of 25 mm, while the fine aggregate consisted of natural sand. Portland pozzolan cement served as the primary cementitious material. Additionally, for mixes aiming for higher compressive strengths (22.39 MPa and above), a retarding admixture was incorporated to prolong the setting times.

2.2. Specimen Preparation

In this research, the examination will concentrate on beam specimens measuring 500 mm × 200 mm × 350 mm. Right after the concrete was mixed, the samples were poured into molds and vibrated 25 times at each third of their height using a vibrator. They were removed from the molds after 24 h, as shown in Figure 1. Table 1 shows the compressive strength for each group of mixes.

Figure 1. Concrete specimens after pouring and vibration.

Table 1. The code for each sample.

Compressive Strength (Mpa)	W/C	Code
14.25 (Mix C)	0.60	C
16.28 (Mix D)	0.60	D
18.32 (Mix E)	0.55	E
20.36 (Mix F)	0.55	F
22.39 (Mix G)	0.45	G
24.43 (Mix H)	0.40	H
28.50 (Mix I)	0.40	I

2.3. Testing Ages

Specimens were tested at 28, 60, 90, and 180 days to evaluate the progression of strength over time. Ten specimens from each mix group were tested at each age. The tests conducted on the specimens included the Windsor Pin Test and the hammer test.

2.4. Rebound Hammer

The rebound hammer test was conducted according to the ASTM C805 guidelines. Before testing, the concrete surface should be examined and smoothed, if necessary, as per ASTM C805. The hammer is pressed against the surface until the spring-loaded mass is released, causing the plunger to strike and rebound. A shear indicator measures the rebound distance, known as the rebound number. At least 10 readings are taken from each testing area [8].

2.5. Windsor Pin Test

The Windsor Pin Test (WPT) is a specialized method for evaluating the compressive strength of concrete, mortar, and brick, conforming to the ASTM C803/C803M [9] and BSI 1881–207:1992 [10] standards. Manufactured by James Instruments Inc., the testing equipment, known as the Windsor Pin Test System®, requires concrete surfaces to be at least 10 mm thick for optimal conditions. It employs a steel pin with a 3 mm diameter and a conical end as the primary probe, with calibration involving meticulous adjustments to ensure proper spring compression.

Correct placement of the device is crucial, requiring a perpendicular orientation to the concrete surface being tested. Activation of the trigger mechanism necessitates maintaining firm contact throughout the testing process. Post-test procedures involve clearing any debris from the hole and then inserting a micrometer to record the depth. The test configuration typically spans from point A to point R, as illustrated in Figure 2a,b.

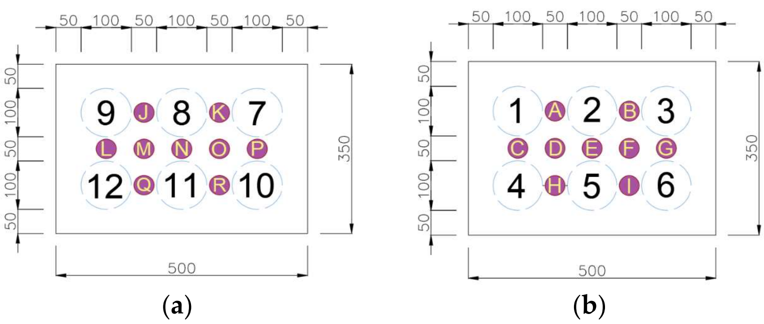


Figure 2. (**a**) Illustration of test configuration; (**b**) illustration of test configuration.

3. Result

3.1. Rebound Number

Figure 3 illustrates a linear regression model employed to plot the rebound number against the concrete's compressive strength, reflecting the linear relationship between the force and deformation of a spring, supported by the rebound curve's linearity provided by the device manufacturer. However, the correlation coefficient (R^2) obtained, which is 0.7894, indicates data dispersion across all samples. This dispersion underscores the influence of factors such as moisture, concrete age, surface smoothness, and environmental exposure on rebound readings and surface hardness. In addition, as the concrete aged from 28 to 180 days, both the actual compressive strength and the estimated strength from the rebound hammer tests notably increased. Despite limitations in precisely predicting the actual strength, the consistent trend in strength increment over time demonstrates the reliability of the rebound hammer test. In the graph, the test results shown in gray are compared with the correlation graph of the rebound number and compressive strength values. The blue line represents the lower 10th percentile curve, and the orange line represents the SilverSchmidt Type N curve from the tool's brochure specifications.

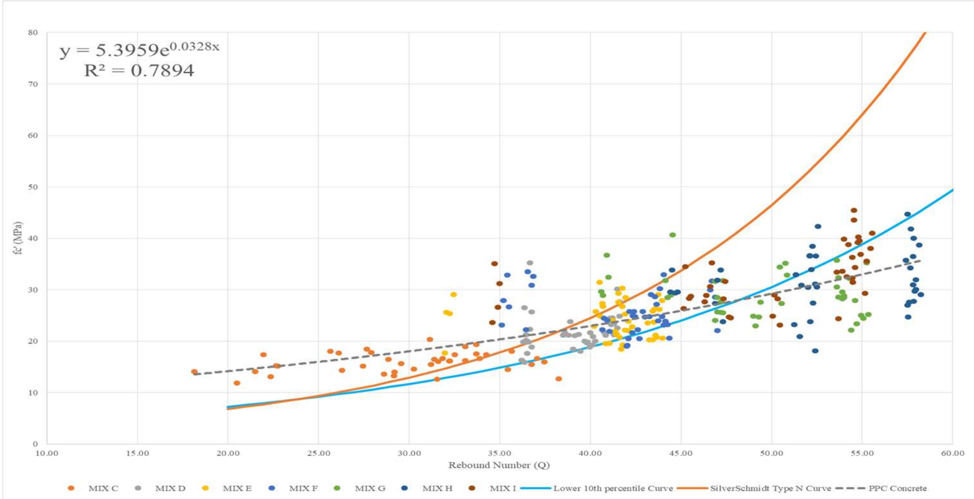
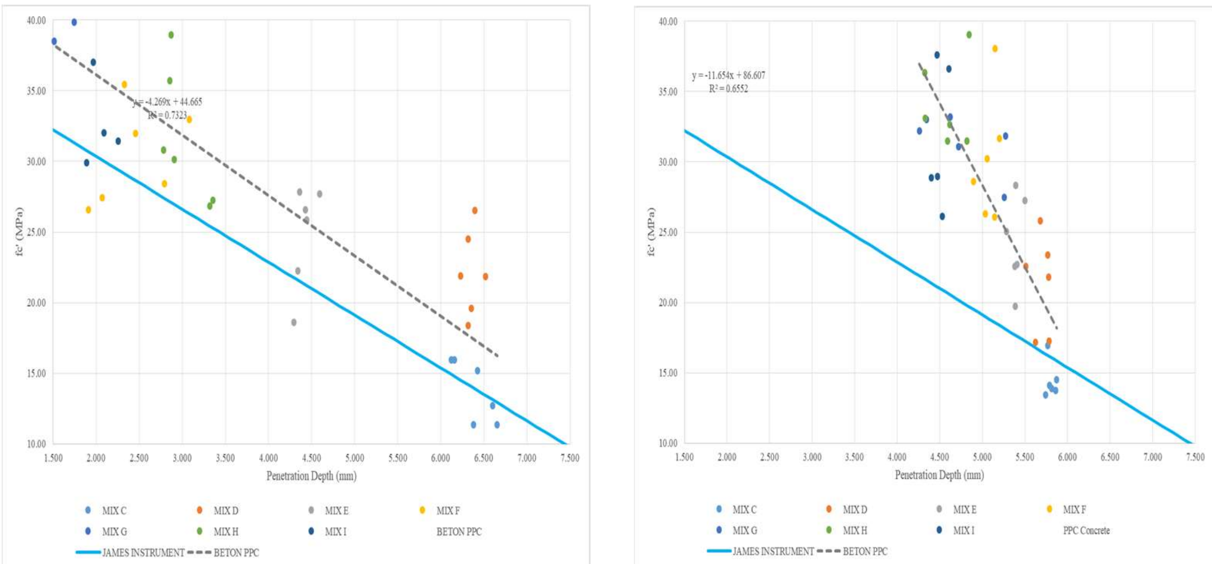


Figure 3. Graphic correlation between rebound number values and compressive strength.

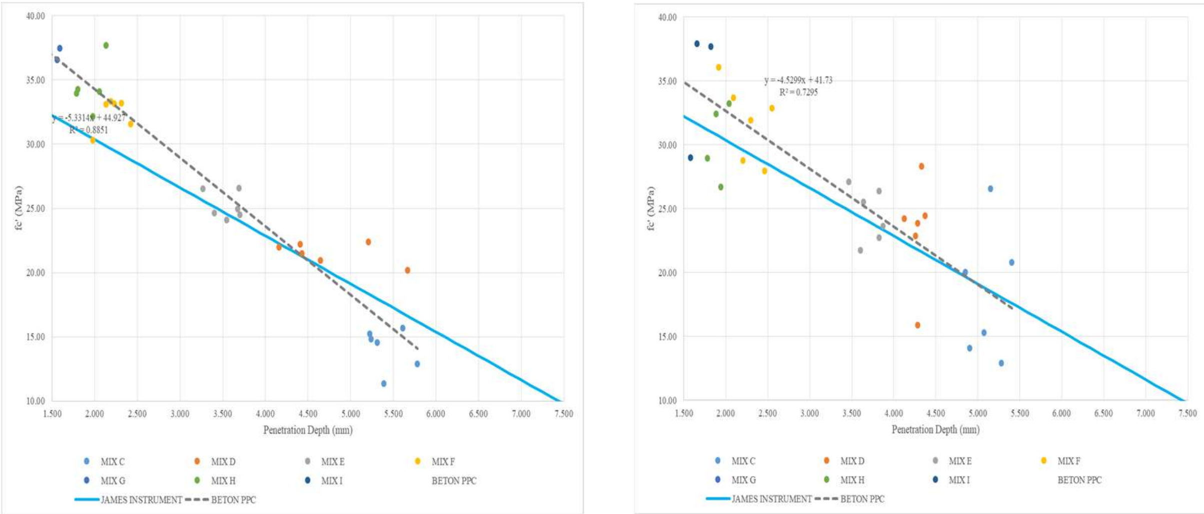
3.2. Penetration Depth

Figure 4a–d represent concrete ages of 28 days, 60 days, 90 days, and 180 days, respectively. All four graphs consistently demonstrate that regardless of concrete age, there is a clear trend indicating that as the penetration depth into the concrete decreases, the concrete's estimated compressive strength increases. In the graph, the test results shown in gray are compared with the correlation graph showing the penetration depth and compressive strength values. The blue line represents the data obtained from the brochure specifications of the Windsor Pin Test tool (James Instrument) provided by the manufacturer. This observation suggests a strong correlation between a decrease in the penetration depth and an increase in the concrete's compressive strength.



(**a**) (**b**)

Figure 4. *Cont.*



(c) **(d)**

Figure 4. (**a**) Comparison at 28 days; (**b**) comparison at 60 days; (**c**) comparison at 90 days; (**d**) comparison at 180 days.

3.3. Penetration Depth of PPC Concrete Development with Age

Figure 5 illustrates the penetration depth data from each test point on the beam samples. The average calculation was performed on all six readings. The data distribution of the penetration depth using the Windsor Pin Test tools indicates an increasing difference in accordance with the planned concrete quality used. At 60 days, the BCN and BDN samples experienced an increase in penetration depth values, while the other samples showed a decrease from their 28-day values. By 90 days, all samples exhibited a decrease in the penetration depth compared to their 60-day values. Finally, at 180 days, the BEN and BIN samples showed an increase, while the other samples showed a decrease in the penetration depth. At the final testing age of 180 days, all samples showed a decrease in the penetration depth compared to that in the initial testing age of 28 days.

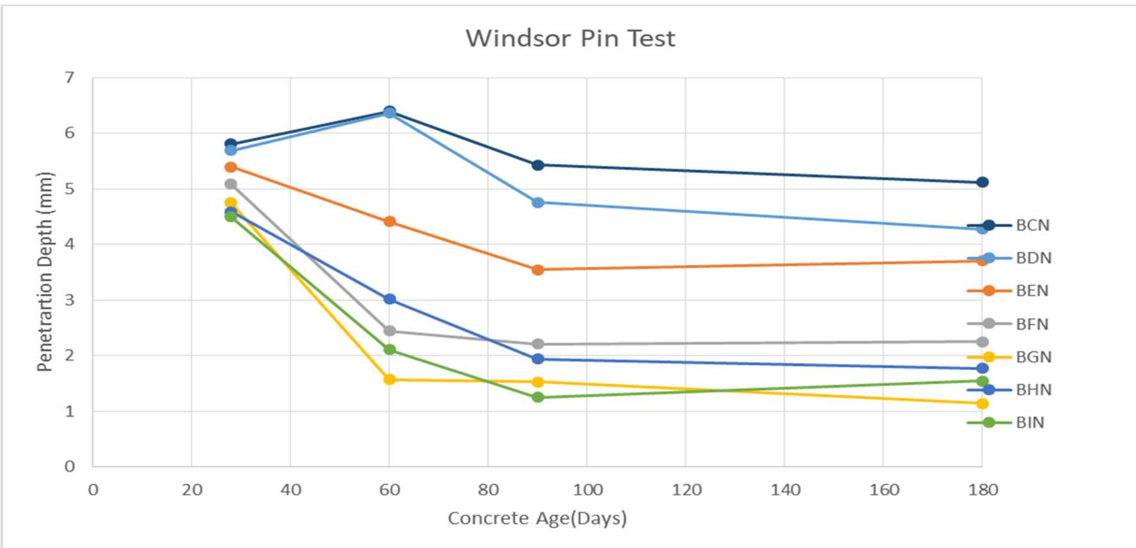


Figure 5. Penetration depth development of PPC concrete with age.

4. Conclusions

This study investigated the development of Portland pozzolan cement (PPC) concrete beyond 28 days. An assessment using the rebound hammer test highlighted its limitations in accurately predicting concrete strength but acknowledged the tool's reliability in tracking gradual strength increases over time. The test results indicate a notable increase in rebound numbers from 28 days to 180 days, ranging from 20 to 60. Conversely, the Windsor Pin Test at 180 days showed a decrease in the penetration depth, ranging from 4 to 7 mm compared to 1 to 6 mm at 28 days, suggesting an increase in the compressive strength as the penetration depth decreases. The correlation between the penetration test and compressive strength of PPC concrete shows a moderately strong relationship. Nevertheless, additional testing with a larger sample size is needed to improve the accuracy of the correlation curve.

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References

1. Hemalatha, T.; Sasmal, S. Early-age strength development in fly ash blended cement composites: Investigation through chemical activation. *Mag. Concr. Res.* **2019**, *71*, 260–270. [CrossRef]
2. Cabané, A.; Pelà, L.; Roca, P. Laboratory and in-situ mechanical characterisation of masonry components by comparing destructive and minor destructive testing techniques. *Constr. Build. Mater.* **2024**, *411*, 134474. [CrossRef]
3. Onyeka, F.C. A Comparative Analysis of the Rebound Hammer and Pullout As Non-Destructive Method in Testing Concrete. *EJENG* **2020**, *5*, 554–558. [CrossRef]
4. Sunarno, Y.; Tjaronge, M.W.; Irmawaty, R. Preliminary Study on Early Compressive Strength of Foam Concrete Using Ordinary Portland Cement (OPC) and Portland Composite Cement (PCC). *IOP Conf. Ser. Earth Environ. Sci.* **2020**, *419*, 012033. [CrossRef]
5. Kencanawati, N.N.; Rawiana, S.; Darmayanti, N.P.R.R. Characteristics of Pozzolan and Composite Portland Cements for Sustainable Concrete Material. *Aceh J. Sci. Technol.* **2020**, *9*, 40–49. [CrossRef]
6. Abd Elrazek, M.; Gamal, Y.A.S. The Reliable Concrete Compression Strength Assessment by SCHMIDT Hammer for Different Concrete Grades. *IOP Conf. Ser. Mater. Sci. Eng.* **2021**, *1171*, 012004. [CrossRef]
7. Kumavat, H.R.; Chandak, N.R.; Patil, I.T. Factors influencing the performance of rebound hammer used for non-destructive testing of concrete members: A review. *Case Stud. Constr. Mater.* **2021**, *14*, e00491. [CrossRef]
8. *ASTM C 805-02*; Standard Test Method for Rebound Number of Hardened Concrete. ASTM: West Conshohocken, PA, USA, 2002.
9. *ASTM C803/C803M-17*; Standard Test Method for Penetration Resistance of Hardened Concrete. ASTM International: West Conshohocken, PA, USA, 2017.
10. *BSI 1881–207:1992*; Testing Concrete. Recommendations for the Assessment of Compressive Strength by Penetration Resistance. British Standards Institution: London, UK, 1992.