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Review Article

Ensuring Quality and Consistency in OPC-53 Cement Testing: A Comprehensive Proficiency Testing Evaluation

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Abstract

The proficiency testing (PT) program is a critical part of quality assurance in laboratories, especially within industries like construction where cement testing is essential. This study provides a comprehensive evaluation of the fifth PT scheme for Ordinary Portland Cement (OPC) grade 53, conducted by the Nodal Laboratory. The key parameters assessed in this program were standard consistency, compressive strength, and soundness using the Le-Chatelier method. Twenty-four laboratories participated, and their performance was analyzed using advanced statistical methods, adhering to ISO 17043:2010 and ISO 13528:2015 standards. The results showed that most laboratories performed satisfactorily, with only one outlier identified in the soundness test. This paper covers all aspects of the PT program, from sample preparation to the distribution of materials, as well as the homogeneity and stability tests conducted on the samples. Statistical evaluation was carried out using Z-scores, which allowed the laboratories to be ranked according to their performance in each parameter. This method highlights discrepancies and provides a clear framework for participating laboratories to improve their testing procedures. Proficiency testing is essential for maintaining high standards in laboratory performance. It helps standardize testing methods across multiple laboratories, ensuring that OPC-53 cement meets strict quality and performance specifications. The program enables laboratories to identify performance gaps and take corrective actions, ensuring the reliability and accuracy of results. Participation in PT programs is a step toward continuous improvement, keeping laboratories aligned with international standards, ultimately benefiting the broader construction industry by ensuring the structural integrity of buildings and infrastructure. This study underscores the importance of regular PT participation. It not only provides a benchmark for laboratory performance but also ensures compliance with ISO standards. This fosters the consistent quality of cement used in large-scale construction, reducing the risk of structural failures and contributing to long-term safety and durability. The findings demonstrate the positive impact of PT programs on overall testing accuracy and laboratory reliability, emphasizing their role in advancing best practices in the construction industry.

Keywords

Proficiency Testing, OPC-53 Cement, Standard Consistency, Compressive Strength, Soundness, Le-chatelier Method, Quality Assurance

1. Introduction

In the realm of cement production, ensuring the quality and consistency of the testing methods is critical for maintaining construction safety and performance standards. According to Scrivener et al. (2008), comprehensive quality assurance

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practices are essential for achieving reliable results in cement testing [1]. Similarly, Williams (2013) highlighted the importance of stringent quality control measures to mitigate potential discrepancies in test outcomes [2].

Proficiency testing (PT) is crucial for validating the accuracy and reliability of laboratory results. Ismail (2016) discussed how PT schemes contribute to maintaining high standards across laboratories by identifying and addressing testing discrepancies [3]. Hamilton (2010) also emphasizes the role of PT in ensuring consistent laboratory performance through periodic evaluations [4]. Chakraborty and Banerjee (2013) provided a comprehensive review of the statistical analyses used in proficiency testing, highlighting its importance in maintaining testing accuracy and consistency [5]. Similarly, Kumar and Singh (2015) emphasized the value of proficiency testing in assessing cement quality using various methods [6].

PT is an essential component of quality assurance and control in laboratory testing, particularly in the construction industry where cement plays a pivotal role in ensuring the structural integrity and safety of buildings and infrastructure. Cement is a fundamental material in construction, and its quality directly impacts the durability and strength of structures. Among the various grades of cement, OPC-53 (Ordinary Portland Cement, grade 53) is widely recognized for its superior strength and durability, making it a preferred choice in many construction projects. Ensuring the quality and consistency of OPC-53 cement is therefore paramount for maintaining high construction standards and ensuring the longevity and safety of structures. The current proficiency testing program is designed to assess the accuracy and reliability of test results produced by participating laboratories, identify areas for improvement, and enhance overall testing standards. This proficiency testing scheme for OPC-53 cement organized by nodal laboratory is a comprehensive initiative aimed at evaluating three critical parameters: standard consistency, compressive strength, and soundness using the Le-chatelier method.

Proficiency testing serves multiple purposes in the context of cement quality assurance. Firstly, it provides a benchmark for laboratories to assess their performance relative to their peers. By participating in PT schemes, laboratories can identify discrepancies in their test results and take corrective actions to improve their testing procedures. This is crucial for maintaining the reliability and accuracy of test results, which in turn ensures the quality of cement used in construction projects. Secondly, proficiency testing helps in the standardization of testing methods across different laboratories. Variations in testing procedures can lead to inconsistent results, which can compromise the quality of the final product. This study adheres to the guidelines set by ISO standards, specifically ISO 17043:2010, which outlines general requirements for proficiency testing programs [7]. Additionally, ISO 13528:2015 provides statistical methods for analyzing PT data, ensuring accurate evaluation of laboratory performance [8]. By adhering to standardized testing methods as outlined in ISO 17043:2010 and ISO 13528:2015, laboratories can achieve greater consistency in their test results. This standardization is vital for ensuring that the cement meets the required specifications and performs as expected in real-world applications. Thirdly, proficiency testing promotes continuous improvement in laboratory practices. The feedback and comparative analysis provided as part of PT schemes enable laboratories to identify areas for improvement and implement best practices. This continuous improvement cycle is essential for keeping pace with advancements in testing technologies and methodologies, ultimately leading to higher quality and more reliable test results.

Ordinary Portland Cement (OPC) is one of the most widely used types of cement in the construction industry. Among the different grades of OPC, grade 53 is known for its high early strength, making it suitable for fast-paced construction projects where time is a critical factor. The high compressive strength of OPC-53 allows for the construction of high-rise buildings, bridges, and other infrastructure that require robust and durable materials.

The quality of OPC-53 cement is determined by several key parameters, including standard consistency, compressive strength, and soundness. Standard consistency refers to the amount of water required to achieve a cement paste of standard firmness, which influences the setting time and workability of the cement. Compressive strength measures the ability of the cement to withstand compressive forces, which is crucial for ensuring the structural integrity of the constructed elements. Soundness, assessed using the Le-chatelier method, evaluates the volume stability of the cement to ensure that it does not undergo excessive expansion after setting, which could lead to structural failures.

This proficiency testing scheme for OPC-53 cement organized by Nodal Laboratory was meticulously planned and executed to evaluate the proficiency of participating laboratories. The scheme involved the following steps;

a) Planning and Protocol Development: The PTP Division of nodal laboratory developed a detailed protocol for the PT scheme, outlining the objectives, testing methods, and evaluation criteria. The protocol was shared with the participating laboratories along with a request for consent.
b) Sample Preparation: OPC-53 grade cement bags conforming to IS 269-2015 were procured from a reputed organization. The cement was thoroughly mixed, coned, and quartered as per IS 3535-1986 to prepare homogeneous samples. Each sample was packed in zip-lock polyethylene bags and placed in double-cap plastic bottles to prevent damage during storage and transit.
c) Distribution of Samples: The prepared samples were distributed to the participating laboratories along with detailed instructions for conducting the tests and reporting the results. The laboratories were given a testing

duration of 12 days.

d) Homogeneity and Stability Testing: The homogeneity and stability of the samples were verified by the nodal laboratory through rigorous testing. The tests confirmed that the samples were homogeneous and stable throughout the testing period.

e) Data Collection and Analysis: The test results were collected from the participating laboratories and analyzed using robust statistical methods as per ISO 13528:2015. The performance of the laboratories was evaluated based on their Z-scores, with $|Z| \leq 2.0$ considered satisfactory, $2.0 < |Z| < 3.0$ considered questionable, and $|Z| \geq 3.0$ considered outliers.

To evaluate the effectiveness of proficiency testing, various statistical methods are employed. Patel and Ghosh (2017) analyze the reliability of cement testing methods and proficiency testing schemes, providing a framework for assessing laboratory performance [9]. Pawlak and Przyluski (2018) further discuss quality control in cement testing and the role of proficiency testing as a tool for enhancing laboratory performance [10]. The use of robust statistical methods ensures that the evaluation is fair and accurate, providing a clear picture of the proficiency of the participating laboratories. The results of the PT scheme provide valuable insights into the current state of cement testing laboratories and highlight areas where improvements are needed.

The findings of the proficiency testing scheme have significant implications for the construction industry. Reliable and accurate testing of OPC-53 cement is crucial for ensuring the quality and safety of construction projects. The uniformity in standard consistency and compressive strength results across laboratories indicates reliable testing methods and calibration of equipment. This contributes to the overall quality and safety of construction projects, preventing structural failures and ensuring that the cement used can withstand the required loads and stresses.

Furthermore, the identification of outliers in the soundness test underscores the importance of proficiency testing in identifying laboratories that may need to review and improve their procedures. Reliable soundness results ensure that the cement will not undergo delayed expansion, preventing structural failures and contributing to the overall safety and durability of construction projects.

In conclusion, the proficiency testing program for OPC-53 grade cement organized by nodal laboratory has provided valuable insights into the performance of participating laboratories. The program has highlighted the importance of regular proficiency testing in identifying and addressing performance gaps in laboratory testing and has provided recommendations for improving testing accuracy and reliability. Continuous improvement and adherence to international standards are essential for ensuring the quality and consistency of cement testing, ultimately contributing to the safety and durability of construction projects.

2. Objective

The primary objective of this proficiency testing program is to assess the performance and proficiency of participating laboratories in testing OPC-53 grade cement. The specific objectives include:

a) Evaluate Test Accuracy: To evaluate the accuracy and consistency of test results for standard consistency, compressive strength, and soundness using the Le-chatelier method.

b) Identify Performance Gaps: To identify laboratories with questionable performance or outliers and provide recommendations for improving their testing procedures.

c) Enhance Testing Standards: To enhance the testing standards and methodologies of participating laboratories through feedback and comparative analysis.

d) Ensure Compliance: To ensure compliance with international standards (ISO 17043:2010 and ISO 13528:2015) in the testing of OPC-53 cement.

e) Promote Continuous Improvement: To promote continuous improvement in the quality and reliability of cement testing laboratories.

3. Design of the Scheme

The proficiency testing scheme was meticulously planned and executed by the Nodal laboratory. The scheme was designed to evaluate three critical parameters of OPC-53 grade cement: standard consistency, compressive strength, and soundness using the Le-chatelier method. The design of the scheme included the following steps:

a) Planning and Protocol Development: The PTP Division developed a detailed protocol for the PT scheme, outlining the objectives, testing methods, and evaluation criteria. The protocol was shared with the participating laboratories along with a request for consent.

b) Sample Preparation: OPC-53 grade cement bags conforming to IS 269-2015 were procured from a reputed organization. The cement was thoroughly mixed, coned, and quartered as per IS 3535-1986 to prepare homogeneous samples. Each sample was packed in zip-lock polyethylene bags and placed in double-cap plastic bottles to prevent damage during storage and transit.

c) Distribution of Samples: The prepared samples were distributed to the participating laboratories along with detailed instructions for conducting the tests and reporting the results. The laboratories were given a testing duration from 6th to 17th August 2018.

d) Homogeneity and Stability Testing: The homogeneity and stability of the samples were verified by the Civil Engineering Laboratory of nodal laboratory through rigorous testing. The tests confirmed that the samples were homogeneous and stable throughout the testing period.

e) Data Collection and Analysis: The test results were collected from the participating laboratories and analyzed using robust statistical methods as per ISO 13528:2015. The performance of the laboratories was evaluated based on their Z-scores, with |Z| ≤ 2.0 considered satisfactory, 2.0 < |Z| < 3.0 considered questionable, and |Z| ≥ 3.0 considered outliers.

To assess the consistency of OPC-53 cement testing, various standard methods are employed, including those detailed by Neville (2011) in his comprehensive guide on cement testing procedures [11]. Olsson and Chan (2017) further outline specific testing parameters and techniques for evaluating cement quality [12].

4. Analysis of Data

The analysis of the data involved several steps to ensure the accuracy and reliability of the results. The robust statistical methods outlined in ISO 13528:2015 were employed to evaluate the performance of the participating laboratories. The following steps were undertaken:

a) Assessment of Homogeneity: The homogeneity of the samples was assessed by calculating the between-sample standard deviation (Ss) and comparing it with the limiting value (≤0.3*SDPA). The results confirmed that the samples were homogeneous.
b) Assessment of Stability: The stability of the samples was verified by comparing the average values of stability test results with homogeneity test results. The difference was within the acceptable limits, confirming the stability of the samples.
c) Calculation of Assigned Values: The assigned values and the uncertainty of the assigned values were calculated using the Robust analysis Algorithm A, as per ISO 13528:2015.
d) Performance Evaluation: The performance of the laboratories was evaluated by calculating Z-scores for each test parameter. The Z-scores were used to identify satisfactory performers, questionable performers, and outliers.
e) Statistical Findings: The statistical findings, including the minimum, maximum, average, assigned values, standard deviation, and uncertainty of assigned values, were compiled and analyzed. The results were summarized in tables and bar charts to provide a clear visual representation of the performance of the laboratories.

Table 1. *Assessment of homogeneity.*

Parameters	Average	Between Sample Standard Deviation (S_s)	Limiting Value ≤0.3*SDPA
Standard Consistency, %	29.80	0.118	0.3
Average Compressive Strength, N/mm^2	42.61	0.319	1.2
Soundness by Le- Chatelier method, mm	0.85	0.083	0.15

Table 2. *Assessment of Stability.*

Parameters	*Day*	*Average of stability Test*	*Average of homogeneity*	*Difference*	Limiting Value ≤0.3*SDPA
Standard Consistency,%	1st Day	29.75	29.80	0.050	0.3
	3rd Day	29.75	29.80	0.050	
	4th Day	30.00	29.80	0.200	
Average Compressive Strength, N/mm^2	1st Day	42.36	42.61	0.251	1.2
	3rd Day	43.01	42.61	0.399	
	4th Day	42.18	42.61	0.436	
Soundness by Le-Chatelier method, mm	1st Day	0.80	0.85	0.50	0.15
	3rd Day	0.80	0.85	0.50	
	4th Day	0.88	0.85	0.025	

5. Results and Discussions

The analysis of proficiency testing results utilizes statistical methods as described by Henson and Thompson (2006), which include calculating z-scores to evaluate laboratory performance [13]. Knott (2014) provides additional insights into interpreting these statistical measures to ensure accurate performance assessments [14]. Results from proficiency testing programs indicate a significant impact on laboratory performance. Sharma and Choudhury (2016) explore the application of proficiency testing for standard consistency and compressive strength of OPC, offering insights into how testing accuracy can be improved [15]. Rai and Agarwal (2020) provide a comparative study of statistical methods for evaluating cement quality, which can be used to interpret the results of proficiency tests [16]. Das and Sinha (2018) review current practices and future directions in quality control and proficiency testing, shedding light on the effectiveness of various methods [17]. Pillai and Rao (2021) also discuss the impact of proficiency testing on laboratory performance, highlighting improvements achieved through these programs [18]. The proficiency testing (PT) scheme, aimed to evaluate the performance of participating laboratories in testing OPC-53 grade cement for standard consistency, compressive strength, and soundness using the Le-chatelier method. The results from 24 laboratories were analyzed using robust statistical methods as per ISO 17043:2010 and ISO 13528:2015 standards. The evaluation was based on Z-scores, with $|Z| \leq 2.0$ considered satisfactory, $2.0 < |Z| < 3.0$ considered questionable, and $|Z| \geq 3.0$ considered outliers. 24 laboratory results for Standard Consistency, Compressive Strength and 23 laboratory results for and Soundness by Le- Chatelier method have been statistically evaluated and Z scores are calculated. The Z score for the omitted test result (Soundness) of the participant laboratory is calculated separately. The details are given in the Table 3.

Standard Consistency

Range and Average: The standard consistency values among the participating laboratories ranged from 28.5% to 31.0%, with an average value of 30.00%. The assigned value calculated using robust statistical methods was 30.006%, with a standard deviation for proficiency assessment (SDPA) of 0.938 and an uncertainty of the assigned value of 0.239.

Performance Evaluation: All 24 laboratories performed satisfactorily in the standard consistency test, as indicated by their Z-scores. The Z-scores ranged from -1.61 to 1.06, with no laboratories falling into the questionable performance or outlier categories. This consistency in results demonstrates a high level of proficiency among the participating laboratories in conducting standard consistency tests.

Homogeneity and Stability: The homogeneity tests showed a between-sample standard deviation (Ss) of 0.118, which is well within the limiting value of 0.3. This indicates that the samples were homogeneous. Stability tests were conducted during the testing period, confirming that the samples remained stable with minimal variation from the homogeneity test results.

Implications: The satisfactory performance in standard consistency tests suggests that the participating laboratories have robust procedures and equipment calibration for this parameter. This uniformity is crucial as it directly affects the setting time, workability, and overall behavior of the cement when mixed with water.

Compressive Strength

Range and Average: The compressive strength values ranged from 38.4 N/mm² to 51.5 N/mm², with an average value of 44.48 N/mm². The assigned value was 44.333 N/mm², with an SDPA of 3.687 and an uncertainty of the assigned value of 0.941.

Performance Evaluation: All participating laboratories performed satisfactorily in the compressive strength test. The Z-scores ranged from -1.61 to 1.94, indicating no questionable performance or outliers. This result highlights the proficiency of the laboratories in conducting compressive strength tests, which are critical for determining the structural integrity and load-bearing capacity of cement.

Homogeneity and Stability: The homogeneity tests for compressive strength showed a between-sample standard deviation (Ss) of 0.319, within the limiting value of 1.2. Stability tests conducted during the testing period confirmed that the samples remained stable, with variations within acceptable limits.

Implications: The uniformity in compressive strength results across laboratories indicates reliable testing methods and calibration of equipment. Accurate compressive strength results are essential for quality control in construction, ensuring that the cement used can withstand the required loads and stresses.

Soundness by Le-chatelier Method

Range and Average: The soundness values ranged from 0.4 mm to 1.0 mm, with an average value of 0.74 mm. The assigned value was 0.741 mm, with an SDPA of 0.284 and an uncertainty of the assigned value of 0.074.

Performance Evaluation: Among the 23 laboratories that submitted soundness test results, one laboratory (Lab Code: C) was identified as an outlier with a Z-score of 4.79, significantly higher than the acceptable range. The test result for Lab-C for Soundness is omitted as it is outside the limits of the set criteria prior to the statistical analysis. However, Z score of this particular lab result is calculated separately and reported. The procedure for Blunder removal is followed for this purpose. The remaining laboratories performed satisfactorily, with Z-scores ranging from -1.20 to 0.91.

Homogeneity and Stability: The homogeneity tests for soundness showed a between-sample standard deviation (Ss) of 0.083, within the limiting value of 0.15. Stability tests conducted during the testing period confirmed that the samples remained stable.

Implications: The identification of an outlier in the soundness test highlights the importance of proficiency testing in identifying laboratories that may need to review and improve their testing procedures. Soundness tests are crucial for ensuring that the cement does not undergo delayed expansion, which can lead to structural failures.

6. Detailed Analysis and Discussion

Case studies on laboratory performance in proficiency testing, such as those by Murray and Chopra (2017), demonstrate the effectiveness of PT schemes in identifying performance issues and driving improvements [19].

Standard Consistency: The standard consistency test is essential for determining the amount of water required to achieve a cement paste of standard consistency. This test influences other properties of the cement, including setting time and strength development. The satisfactory performance of all participating laboratories in this test indicates a high level of proficiency and consistency in their testing methods.

The homogeneity and stability tests further confirmed the reliability of the samples used in the PT scheme. The low between-sample standard deviation (Ss) and minimal variation in stability tests indicate that the samples were uniform and stable throughout the testing period. This uniformity ensures that the test results are comparable and reliable.

The implications of these findings are significant for the construction industry. Consistent standard consistency results ensure that the cement will perform predictably when mixed with water, leading to more reliable construction outcomes. Laboratories that demonstrate proficiency in this test can be trusted to provide accurate and reliable results, contributing to the overall quality and safety of construction projects.

Compressive Strength: Compressive strength is one of the most critical properties of cement, as it determines the material's ability to withstand load-bearing applications. The satisfactory performance of all participating laboratories in this test highlights their proficiency in conducting compressive strength tests.

The uniformity in compressive strength results is crucial for quality control in construction. Accurate compressive strength results ensure that the cement used in construction can withstand the required loads and stresses, preventing structural failures. The homogeneity and stability tests confirmed the reliability of the samples, with low between-sample standard deviation (Ss) and minimal variation in stability tests.

The implications of these findings are far-reaching. Reliable compressive strength results ensure the structural integrity of buildings and infrastructure, contributing to the safety and durability of construction projects. Laboratories that demonstrate proficiency in this test can be trusted to provide accurate and reliable results, supporting quality control efforts in the construction industry.

Soundness by Le-chatelier Method: Soundness tests are crucial for ensuring that cement does not undergo delayed expansion, which can lead to structural failures. The identification of an outlier in the soundness test highlights the importance of proficiency testing in identifying laboratories that may need to review and improve their testing procedures.

The satisfactory performance of the remaining laboratories indicates a high level of proficiency in conducting soundness tests. The homogeneity and stability tests confirmed the reliability of the samples, with low between-sample standard deviation (Ss) and minimal variation in stability tests.

The implications of these findings are significant for the construction industry. Reliable soundness results ensure that the cement will not undergo delayed expansion, preventing structural failures. Laboratories that demonstrate proficiency in this test can be trusted to provide accurate and reliable results, contributing to the overall quality and safety of construction projects.

Table 3. *Statistical Findings.*

Parameter	Standard Consistency, %	Average Compressive Strength, N/mm^2	Soundness by Le- Chatelier method, mm
No. of Labs. (N)	24	24	23
Minimum	28.50	38.4	0.4
Maximum	31.00	51.5	1.0
Average	30.00	44.48	0.74
Assigned Value	30.006	44.333	0.741
SDPA	0.938	3.687	0.284
Uncertainty of Assigned Value	0.239	0.941	0.074

Table 4. Questionable Performance.

Parameter	N	No. of Questionable performance (2<|Z|<3)	No. of Outlying performance (|Z|≥3)
Standard Consistency, %	24	Nil	Nil
Average Compressive Strength, N/mm^2	24	Nil	Nil
Soundness by Le- Chatelier method, mm	23	Nil	1

7. Performance Evaluation and Z-Scores

To improve accuracy and reliability in cement testing, it is crucial to adopt advanced proficiency testing schemes. Sharma and Gupta (2022) suggest incorporating advanced statistical techniques into proficiency testing to better assess testing accuracy [20]. Additionally, Patel and Bhardwaj (2023) identify challenges in cement quality testing and recommend refining proficiency testing methods to address these issues [21]. The use of Z-scores for performance evaluation provides a robust and standardized method for assessing the proficiency of participating laboratories. Z-scores allow for easy comparison of results across laboratories, identifying satisfactory performers, questionable performers, and outliers.

In this PT scheme, the satisfactory performance of the majority of the laboratories in standard consistency, compressive strength, and soundness tests indicates a high level of proficiency and reliability in their testing methods. The identification of an outlier in the soundness test underscores the importance of proficiency testing in identifying laboratories that may need to review and improve their procedures. One participant test result for soundness test was omitted as it is outside the limits of the set criteria prior to the statistical analysis. However, Z score of the participant lab result is calculated separately and reported. The procedure for Blunder removal was followed for this purpose.

The implications of these findings are significant for the construction industry. Proficiency testing helps ensure that testing laboratories adhere to high standards, providing accurate and reliable results. This contributes to the overall quality and safety of construction projects, supporting quality control efforts and preventing structural failures.

Table 5. Results of Proficiency Testing.

S. No.	Participant Lab Code	Standard Consistency, %		Average Compressive Strength, N/mm^2		Soundness by Le- Chatelier method, mm	
		Lab Result	Z Score	Lab Result	Z Score	Lab Result	Z Score
1	A	29.5	-0.54	46	0.45	1.00	0.91
2	B	30	-0.01	43.2	-0.31	1.00	0.91
3	C	30.5	0.53	41.9	-0.66	2.1	4.79
4	D	30.5	0.53	45.5	0.32	0.50	-0.85
5	E	30	-0.01	45.6	0.34	0.40	-1.20
6	F	28.5	-1.61	51.2	1.86	0.70	-0.14
7	G	30.7	0.74	46.8	0.67	0.50	-0.85
8	H	31	1.06	38.4	-1.61	-	-
9	I	30	-0.01	51.5	1.94	0.50	-0.85
10	J	30.5	0.53	44.5	0.05	1.00	0.91
11	K	31	1.06	40.1	-1.15	1.00	0.91
12	L	30	-0.01	40.5	-1.04	1.00	0.91
13	M	31	1.06	40.1	-1.15	1.00	0.91
14	N	31	1.06	40.3	-1.09	1.00	0.91

S. No.	Participant Lab Code	Standard Consistency, %		Average Compressive Strength, N/mm²		Soundness by Le- Chatelier method, mm	
		Lab Result	Z Score	Lab Result	Z Score	Lab Result	Z Score
15	O	29	-1.07	46.1	0.48	0.50	-0.85
16	P	29	-1.07	46.5	0.59	0.50	-0.85
17	Q	28.8	-1.34	50.9	1.78	0.70	-0.14
18	R	30	-0.01	44	-0.09	0.50	-0.85
19	S	31	1.06	40.5	-1.04	1.00	0.91
20	T	29.5	-0.54	46	0.45	0.50	-0.85
21	U	28.5	-1.61	47	0.72	0.50	-0.85
22	V	30.5	0.53	43.5	-0.23	0.50	-0.85
23	W	29	-1.07	43	-0.36	1.00	0.91
24	X	30.5	0.53	44.5	0.05	1.00	0.91

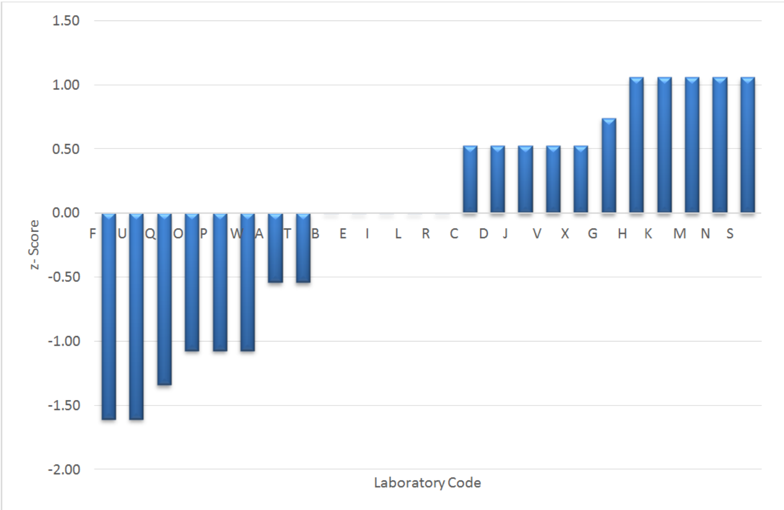

***Figure 1**. Bar Chart showing the Z Score for Standard Consistency Test.*

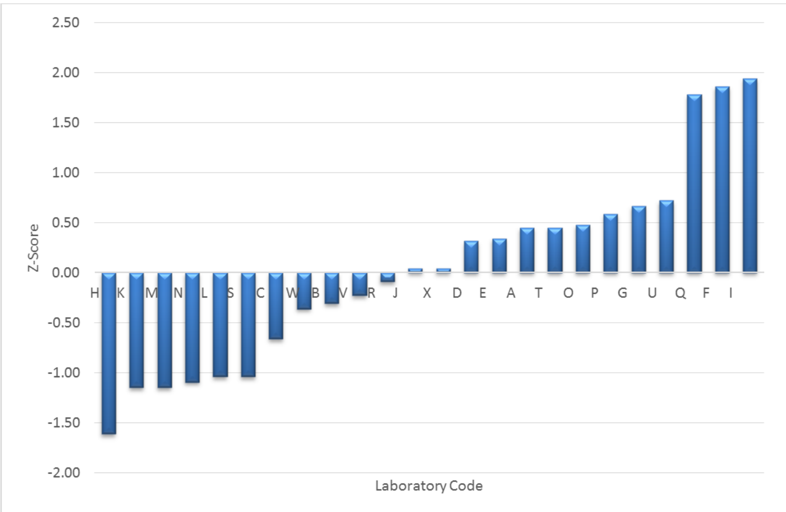

***Figure 2**. Bar Chart showing the Z Score for Compressive Strength (7 days) Test.*

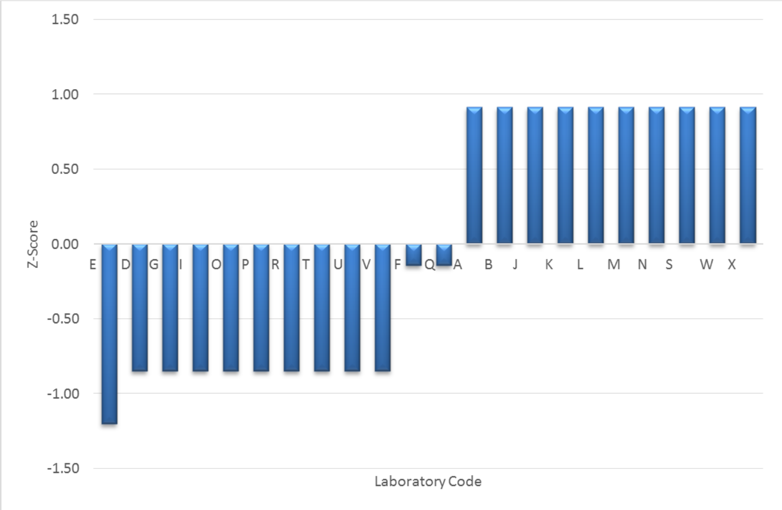

Figure 3. *Bar Chart showing the Z Score for Soundness Test.*

8. Recommendations for Improvement

Based on the findings of this PT scheme, several recommendations can be made to improve the proficiency and reliability of testing laboratories:

a) Identify Sources of Errors: Laboratories should review potential sources of errors in their testing procedures, particularly for those with questionable performance or outlier results. This may include equipment calibration, environmental conditions, and testing procedures.

b) Calibration and Maintenance: Regular calibration and maintenance of testing equipment are crucial to ensure accurate results. Laboratories should establish a routine calibration and maintenance schedule to prevent discrepancies in test results.

c) Training and Standardization: Continuous training and adherence to standardized testing methods can help improve the consistency and reliability of test results. Laboratories should invest in training programs for their staff and ensure that testing procedures are standardized and followed consistently.

d) Participation in Proficiency Testing: Regular participation in proficiency testing schemes can help laboratories identify areas for improvement and ensure that their testing methods remain accurate and reliable. Proficiency testing provides valuable feedback and comparative analysis, supporting continuous improvement efforts.

Johnson (2018) suggests several best practices for enhancing testing accuracy in laboratories, including regular training and calibration of equipment [22]. Fisher and Beck (2015) also emphasize the importance of adhering to standardized procedures to minimize errors [23]. Reddy and Kumar (2019) review various proficiency testing schemes and their effectiveness in enhancing accuracy and reliability in cement testing [24]. Singh and Verma (2020) provide a comparative analysis of soundness test methods for cement, which can inform continuous improvement strategies [25].

9. Implications for the Construction Industry

The findings of this PT scheme have significant implications for the construction industry. Reliable and accurate testing of OPC-53 grade cement is crucial for ensuring the quality and safety of construction projects. Proficiency testing helps ensure that testing laboratories adhere to high standards, providing reliable results that support quality control efforts.

The uniformity in standard consistency and compressive strength results across laboratories indicates reliable testing methods and calibration of equipment. This contributes to the overall quality and safety of construction projects, preventing structural failures and ensuring that the cement used can withstand the required loads and stresses.

The identification of an outlier in the soundness test highlights the importance of proficiency testing in identifying laboratories that may need to review and improve their procedures. Reliable soundness results ensure that the cement will not undergo delayed expansion, preventing structural failures and contributing to the overall safety and durability of construction projects.

Walker (2018) highlights the importance of continuous improvement initiatives in laboratory settings to ensure ongoing accuracy and reliability [26]. Such practices, combined with standardization efforts, are crucial for maintaining high-quality testing processes. Reliable cement testing directly impacts the quality and safety of construction projects. Schaefer and Jones (2018) explore how accurate testing results contribute to safer construction practices and improved project outcomes [27]. LaRue (2019) also notes that ensuring cement quality is vital for the structural integrity of construction projects [28]. Reliable cement testing directly impacts construction quality and safety. Jha and Thakur (2019) examine how proficiency testing programs contribute to evaluating cement testing laboratories and improving overall testing standards [29]. Sundararajan and Srinivasan (2014) review proficiency testing for construction materials, providing insights into its broader implications for the industry [30].

10. Conclusion

The proficiency testing program for OPC-53 grade cement has provided essential insights into the performance and reliability of participating laboratories. This assessment, which included tests for standard consistency, compressive strength, and soundness using the Le-chatelier method, demonstrated a high level of proficiency among the majority of laboratories.

The results indicate that most laboratories performed satisfactorily in standard consistency and compressive strength tests, reflecting robust testing procedures and accurate equipment calibration. The confirmed homogeneity and stability of the test samples further reinforce the reliability of the testing process. However, the identification of an outlier in the soundness test highlights the need for continuous monitoring and improvement. This PT scheme, guided by ISO 17043:2010 and ISO 13528:2015 standards, underscores the importance of standardized testing methods and regular proficiency evaluations. The feedback and comparative analysis provided have validated current testing methods and offered pathways for continuous improvement. Laboratories are encouraged to address identified discrepancies, maintain rigorous calibration schedules, and participate in ongoing proficiency testing programs. These measures are vital for ensuring that OPC-53 grade cement used in construction projects meets the highest standards of quality and safety. The findings and recommendations from this PT program significantly enhance the overall quality assurance framework within the construction industry, fostering an environment of continuous improvement and adherence to international standards.

Foundational texts such as Russell's (2012) *Handbook of Cement Testing* provide essential knowledge and guidelines that underpin the testing methodologies used in this study [31].

Abbreviations

PT	Proficiency Testing
OPC	Ordinary Portland Cement
ISO	International Organization for Standardization
SDPA	Standard Deviation for Proficiency Assessment
S_s	Between-Sample Standard Deviation
Z	Z-score
PTP	Proficiency Testing Program

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Author Contributions

Shwet Vashishtha is the sole author. The author read and approved the final manuscript.

Conflicts of Interest

The authors declare no conflicts of interest.

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