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Review Article

Quality Assessment and Inter-Laboratory Comparison of High-Density Polyethylene Pipes for Water Supply Applications

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Abstract - *The study focuses on an Inter Laboratory Comparison (ILC) program for polyethylene (PE) pipes used in water supplies, conducted in accordance with IS 4984:2016. The program's objective was to evaluate the consistency and accuracy of laboratory results across 11 participating laboratories, covering key performance parameters such as Melt Flow Rate (MFR), density, wall thickness, elongation at break, and carbon black content. These parameters are critical to assessing PE pipes' long-term durability and safety, which are essential in water distribution infrastructure. The ILC program results revealed varying accuracy and repeatability levels among the participating laboratories. While most laboratories demonstrated acceptable consistency in measuring density and wall thickness, discrepancies were observed in MFR and elongation results, suggesting a need for stricter control over testing conditions and equipment calibration. Carbon black content, crucial for UV resistance, was measured consistently across laboratories, aligning with IS 4984:2016 specifications. The study highlights several areas for improvement in laboratory procedures, especially regarding the testing of MFR and elongation. These parameters are sensitive to variations in testing conditions, and stricter standardization is recommended to ensure more reliable results. The findings have significant implications for the polyethylene pipe industry, particularly ensuring that quality control processes are robust enough to meet the growing demand for water supply infrastructure. The ILC program underscores the importance of continuous training for laboratory personnel and the adoption of standardized methodologies to enhance the reliability of test results across different facilities. In conclusion, this ILC program has identified key areas for procedural refinement. It emphasizes the need for ongoing quality assurance in PE pipe manufacturing, ultimately contributing to safer and more reliable water distribution systems.*

Keywords - *High-density polyethylene pipes, Melt flow rate, Carbon black content, Hydrostatic strength, Water supply piping.*

1. Introduction

Polyethylene pipes have a long history dating back to the mid-20th century. The first polyethylene resins were developed in the 1930s, and by the 1950s, polyethylene pipes were being used for gas and water distribution. In the 1960s and 1970s, developing High-Density Polyethylene (HDPE) resins led to the production of HDPE pipes with improved strength, stiffness, and resistance to corrosion and scaling. These properties made HDPE pipes an attractive alternative to traditional materials like steel and concrete for water supply applications. Over the decades, advancements in extrusion technology and the formulation of HDPE resins have further enhanced the performance and durability of HDPE pipes. Today, HDPE pipes are widely used in water distribution systems globally due to their high durability, chemical resistance, and flexibility. The ongoing research and development of HDPE pipes continue to improve their quality and sustainability, ensuring they remain a reliable component of water infrastructure in the future. Polyethylene pipes have become integral to modern water supply systems due to their high durability, chemical resistance, and flexibility. Among the different types of polyethylene pipes, High-Density Polyethylene (HDPE) pipes are widely used in applications such as potable water distribution, sewage systems, and irrigation. The Indian Standard IS 4984:2016 outlines the specifications for polyethylene pipes used for water supplies, covering various critical parameters to ensure performance and longevity in diverse environmental conditions. The IS 4984:2016 standard, established by the Bureau of Indian Standards, outlines the specifications and testing requirements for polyethylene pipes used in water supply systems. In the context of this study, all 11 participating laboratories conducted tests on the HDPE pipe samples in accordance with the guidelines outlined in IS

4984:2016. This included the determination of Melt Flow Rate, Density, Wall Thickness, Elongation at Break, and Carbon Black content using the methods prescribed in the standard. Adherence to IS 4984:2016 ensured uniformity in testing procedures across all laboratories, providing a consistent basis for comparing results and assessing inter-laboratory variability. The growing demand for efficient water distribution systems has made the quality assessment of polyethylene pipes a focal research point. Several factors influence the performance of polyethylene pipes, including their Melt Flow Rate (MFR), Density, Wall Thickness, Elongation at break, and Carbon Black content. These parameters are essential for understanding the pipes' mechanical properties, thermal stability, and weathering resistance. For instance, the Melt Flow Rate measures the viscosity of the molten polymer and directly correlates to its processability and long-term strength under operational pressures. The Density of polyethylene pipes is another crucial parameter as it affects their stiffness, tensile strength, and overall durability.

The relationship between density and pipe performance has been thoroughly researched, showing that higher density typically enhances the mechanical properties of the pipe. However, improper density adjustments can lead to brittleness, which may result in pipe failure under high-stress conditions. Similarly, Wall Thickness is directly related to the pipe's pressure rating and resistance to external loads, making it an important factor in assessing the structural integrity of water supply pipes. Another critical factor is Elongation at Break, which assesses the flexibility and ductility of polyethylene pipes under tensile stress. Pipes with high elongation values can better withstand deformation under stress, reducing the risk of breakage in fluctuating environmental conditions. This property is particularly important for underground applications, where soil movement can exert additional pressure on the pipes.

Furthermore, Carbon Black (CB) is added to polyethylene pipes to protect them from UV radiation and thermal degradation. The distribution and amount of carbon black significantly influence the durability of the pipes, especially when they are exposed to sunlight or high temperatures over extended periods. Studies have demonstrated that improper distribution of carbon black can lead to early pipe failures due to uneven thermal expansion and degradation [1]. Proper dispersion of carbon black not only improves the longevity of the pipes but also maintains their mechanical strength and flexibility.The analysis of High-Density Polyethylene (HDPE) pipes reveals that many do not conform to established quality standards, potentially reducing project lifespan. This study aimed to evaluate the quality of HDPE pipes through laboratory tests on 21 specimens from various manufacturers, comparing results against the Nepal Bureau of Standards and Metrology (NS 402042). Both qualitative and quantitative data were collected, showing that while Nepalese HDPE pipes generally met quality standards, some manufacturers deliberately reduced pipe weight to pass laboratory tests. It is recommended that NS 40 certificates be mandatory and that quality assurance measures, including procurement based on length and weight, be implemented. Additionally, establishing regional testing laboratories and reassessing transportation costs will enhance the procurement process for HDPE pipes [2].

High-Density Polyethylene (HDPE) has emerged as a preferred material for culverts and drainage pipelines due to its many advantages, including durability and longevity. Over the past several years, research has focused on the service-life expectancy of HDPE pipes made from recycled versus virgin resins, with studies indicating a potential lifespan exceeding 100 years. However, environmental conditions and service criteria significantly influence this durability. Concerns raised by Quebec's Ministry of Transportation (MTQ) have highlighted the need for clarity in assessing the performance of HDPE pipes under various exposure scenarios, particularly in northern climates.

This research paper reviews critical factors affecting HDPE pipe longevity, including methodologies for predicting durability—such as creep rupture strength, stress crack resistance, and oxidation—while also addressing the performance of pipes made from recycled materials for infrastructure applications [3]. One research investigates the leakage behavior of High-Density Polyethylene (HDPE) pipes, which are particularly sensitive to pressure, especially concerning longitudinal slits—common failure points in water distribution networks. The study is conducted on a semi-industrial pilot scale and introduces new criteria for assessing variations in leak areas that exhibit either elastic or plastic behavior.

Findings reveal that these slits can demonstrate plastic behavior even under normal pressure conditions. The leakage exponent ranges from 0.44 to 1.44 in the elastic phase, increasing upto 2 during the plastic phase. The outcomes provide valuable methods for estimating leakage amounts and inform strategies for reducing leaks, including evaluating factors such as water temperature and calculating discharge coefficients in longitudinal slits [4]. Another research focuses on the mechanical behavior of High-Density Polyethylene (HDPE) pipes used in water supply networks, driven by the need to replace and modernize infrastructure in a city with 300,000 residents. It presents findings related to HDPE's mechanical properties, a thermoplastic known for its numerous advantages in pipe manufacturing. Experimental data was gathered to assess the material's performance in two configurations: pipes buried underground and those supported by concrete massifs. The study highlights the benefits of the latter configuration and examines cracking behavior in HDPE pipes using classical models.

Additionally, pipe and elbow cracking simulations were conducted, providing valuable insights for network users [5]. The Inter Laboratory Comparison (ILC) Program is a method used to assess and compare the performance of polyethylene pipes by evaluating these parameters across different laboratories. The ILC aims to ensure consistency and reliability in testing methods, providing robust data for manufacturers and regulatory bodies to improve product quality. This paper focuses on the results of an ILC conducted among 11 laboratories for HDPE pipes used in water supplies. The laboratories tested the samples for Melt Flow Rate, Density, Wall Thickness, Elongation, and Carbon Black content according to IS 4984:2016, highlighting variations in results and improvement in testing consistency [6-8]. By assessing these parameters across multiple laboratories, the study aims to standardize testing methods and contribute to the ongoing enhancement of polyethylene pipe quality for water supply systems. The findings will serve as a foundation for further research and development, ensuring that polyethylene pipes remain a reliable component of water infrastructure in the future.

1.1. Importance of ILC in PE Pipe Testing

Interlaboratory Comparison (ILC) programs play a crucial role in ensuring the accuracy and reliability of testing methods across different laboratories. For polyethylene (PE) pipes used in water supply, ILCs are vital to maintaining the standard quality of pipes produced by various manufacturers. They help identify discrepancies in test results, ensuring consistency in assessing parameters such as Melt Flow Rate, Density, Wall Thickness, Elongation, and Carbon Black content. This comparison allows laboratories to align their methods with international or national standards, improving overall product quality and safety.

1.2. Overview of ILC on PIPE Testing

An ILC involves different laboratories testing identical samples to compare and validate results. The primary aim is to enhance testing precision and identify any deviations in laboratory methodologies. In PE pipes, ILCs follow specific standards like IS 4984:2016, which outlines the testing requirements for pipes used in water supplies. This standard provides detailed specifications for assessing critical factors influencing PE pipes' long-term performance and durability. The primary aim of this ILC was to evaluate the inter-laboratory variability in the results of these 5 test parameters. Identifying inconsistencies across labs allows a deeper understanding of the methodologies' precision. It also allows labs to improve their testing processes by aligning them more closely with the standard. The ability of laboratories to produce accurate and reproducible results is essential for ensuring quality control within the PE pipe industry.

1.3. Parameters Tested and their Significance

- Melt Flow Rate (MFR): This parameter measures the ease of flow of molten PE material, directly impacting the pipe's processability and strength. A higher MFR may indicate better flow but lower mechanical strength, making it a balancing act during manufacturing.
- Density: Higher density results in better stiffness and tensile strength, which is critical for pipes under pressure. This parameter is central to determining the pipe's load-bearing capacity.
- Wall Thickness: This factor is key to assessing the pipe's ability to withstand internal pressure and external environmental loads, ensuring long-term structural integrity.
- Elongation at Break: High elongation values indicate good flexibility, which is essential for pipes laid in terrains with ground movement or subject to temperature variations.
- Carbon Black Content: Carbon black provides UV protection, preventing thermal degradation. Its uniform distribution ensures the longevity of pipes exposed to sunlight.

1.4 Challenges and Insights from the ILC Study

Some of the primary challenges identified in the ILC study include discrepancies in testing methodologies, resulting in variations in the test results. Laboratories may use different instruments or testing environments, leading to inconsistent outcomes. Additionally, interpreting complex parameters such as Melt Flow Rate and Carbon Black content requires precise calibration, which some labs may lack. These challenges highlight the need for more rigorous standardization and regular participation in ILCs to ensure continual improvement. ILCs also provide insights into potential areas for improvement, such as the refinement of test methods, retraining of laboratory personnel, and introducing more stringent controls to minimize errors during testing. The findings of the ILC study will contribute to better-quality PE pipes, enhancing their performance in water supply systems.

2. Objective

The primary objective of the Inter Laboratory Comparison (ILC) program on polyethylene (PE) pipes for water supplies, as per IS 4984:2016, is to assess the accuracy and consistency of laboratory testing methods across multiple laboratories. By comparing the results from 11 participating labs, the program aims to:

- Ensure uniformity in testing methodologies.
- Identify discrepancies or deviations in results.
- Improve the quality and reliability of the tests conducted on critical parameters such as Melt Flow Rate (MFR), Density, Wall Thickness, Elongation, and Carbon Black content.
- Facilitate compliance with national and international standards for PE pipes, ensuring product safety and performance over time.

3. Design of the Scheme

The design of the ILC program involves:

- Sample Distribution: Identical samples of PE pipes are distributed to 11 laboratories. These samples conform to IS 4984:2016 specifications for water supply applications.
- Parameter Testing: Each lab is tasked with testing the same parameters—MFR, Density, Wall Thickness, Elongation at Break, and Carbon Black content—using their standard methods.
- Result Compilation and Comparison: Once the tests are completed, the results from all participating labs are compiled and analyzed. Statistical methods are applied to assess the variability between laboratories.
- Feedback and Improvement: The data highlights potential deviations and suggests testing protocol improvements, ensuring alignment with the IS 4984:2016 standard.

4. Materials and Methods

4.1. Materials

Polyethylene Pipe Samples: The samples used for testing were high-density polyethylene (HDPE) pipes, conforming to the specifications of IS 4984:2016. These pipes are designed for potable water supplies and have specific characteristics such as thickness, density, and resistance to wear.

4.2. Test Parameters

- Melt Flow Rate (MFR): This measures the flow of the polymer at a specific temperature and pressure, determining its viscosity and processing behavior.
- Density: The mass per unit volume is crucial for understanding the material's mechanical strength.
- Wall Thickness: Measured to ensure uniformity and compliance with IS 4984:2016.
- Elongation at Break: This tests the ductility and flexibility of the pipe under stress.
- Carbon Black Content: Measures the pipe's resistance to UV degradation. Measuring Carbon Black content in polyethylene pipes involves specialized testing techniques to determine the amount and distribution of carbon black in the material. One common method is infrared spectroscopy, which can quantify the absorption of infrared radiation by the carbon black particles. Another method is Thermogravimetric Analysis (TGA), which involves heating the sample in a controlled atmosphere and measuring the weight loss due to the polymer's decomposition and the carbon black's oxidation. The residue remaining after TGA corresponds to the carbon black content.

These testing methods should follow established standards, such as IS 4984:2016, to ensure accurate and reliable results. The consistent measurement of carbon black content is critical, as it directly influences the UV resistance and long-term durability of the HDPE pipes. Standardizing the testing conditions for Melt Flow Rate (MFR) and Elongation at Break is crucial to minimize variability and ensure consistency across different laboratories. For MFR testing, strictly controlling the temperature at 190°C ± 0.5°C, as specified in IS 4984:2016, is essential. Additionally, the same type of MFR testing equipment should be used across all laboratories, and the equipment must be regularly calibrated to ensure accurate results. Furthermore, the testing procedure, including the loading and unloading of the sample, should be performed consistently. For Elongation at Break testing, the specimens should be prepared according to the standard, and the testing machine should be set at a constant rate of grip separation. The ambient temperature and humidity should also be controlled during testing. By standardizing these testing conditions, laboratories can reduce variability and improve the comparability of MFR and Elongation at Break results.

4.3. Methods

- Sample Preparation: Identical PE pipe samples were distributed to all 11 participant laboratories.
- Testing Procedure:
  - Laboratories conducted the tests in accordance with IS 4984:2016 guidelines.
  - Each lab tested the samples' MFR, Density, Wall Thickness, Elongation, and Carbon Black content.
- Data Collection: Results from all laboratories were collected and compiled for comparison.
- Statistical Analysis: The results were analyzed to identify deviations and discrepancies between labs, applying statistical methods for consistency and accuracy assessment.

The 11 participating laboratories conducted tests using identical pipe samples and procedures. Each lab was provided with clear instructions and followed the IS 4984:2016 guidelines to ensure uniformity. After conducting the tests, the results from all laboratories were compiled, analyzed, and compared to assess inter-laboratory variability and identify any significant deviations from the expected values. The data was subjected to statistical analysis to evaluate the precision and reproducibility of each laboratory's results. Parameters such as standard deviation, coefficient of variation, and z-scores were calculated to compare the performance of the laboratories.

5. Results and Discussion

5.1. Results

The Inter Laboratory Comparison (ILC) for Polyethylene Pipes for Water Supplies as per IS 4984:2016 was conducted across 11 laboratories, with the results provided for five critical parameters: Melt Flow Rate, Density, Elongation, Carbon Black Content, and Wall

Thickness. Each laboratory's performance was compared based on Z-scores, indicating how much their measurements from the average.

- Melt Flow Rate: The average Melt Flow Rate was 0.519, with a Standard Deviation (SD) of 0.064. Labs like Lab-H had a higher Z-score (1.89), indicating higher values for this parameter, whereas Lab-G had the lowest Z-score (-1.08), deviating significantly from the group average. Labs with Z-scores closer to zero, such as Lab-A, were in closer agreement with the mean.
- Density: The average density was 951.8 kg/m³ (SD: 2.7). Lab-F showed the highest deviation with a Z-score of 1.93, while Lab-D showed a negative Z-score (-1.04), indicating lower density measurements.
- Elongation: This parameter had an average of 694.1 with a relatively high standard deviation of 160.9, indicating variability across laboratories. Lab-F had the highest elongation at 1001 with a Z-score of 1.90, while Lab-E had an outlying low value of 329, corresponding to a Z-score of -2.27.
- Carbon Black Content: The average Carbon Black content was 2.397% (SD: 0.208). Lab-H showed the highest content at 2.63% (Z-score of 1.12), while Lab-I showed a significantly lower value of 2.10% with a negative Z-score (-1.43).
- Wall Thickness (Min and Max): The average minimum wall thickness was 3.795 mm (SD: 0.023), while the maximum wall thickness averaged 3.940 mm (SD: 0.055). Lab-I had the thickest walls, with maximum thickness at 4.02 mm (Z-score 1.47), while Lab-D had the lowest wall thickness values.

5.2. Discussion

The results of the ILC reveal important insights into the precision and consistency of testing across laboratories. Several key observations can be made:

- Consistency and Accuracy: Laboratories such as Lab H consistently exhibited higher values across several parameters, such as Melt Flow Rate and Carbon Black content. This could suggest a systematic difference in testing methodology or calibration compared to other labs. In contrast, Labs I and Lab E showed lower results in multiple areas, possibly indicating underperformance or calibration issues.
- Z-Score Implications: The Z-scores for each parameter indicate how much laboratories deviate from the mean. Laboratories with Z-scores close to zero are performing well in comparison to others. However, significant deviations—such as a Z-score of -2.27 for elongation in Lab E—suggest that further investigation may be needed to identify the cause of such variation.
- Variability in Elongation: The elongation results show the greatest data spread with a high SD of 160.9. Labs like Lab F and Lab E stand out, with Lab F reporting the highest elongation and Lab E reporting extremely low elongation. These results may reflect differences in material handling, environmental factors, or calibration in tensile testing machines.
- Carbon Black Content: The wide range of Carbon Black content values, from 2.10% to 2.63%, shows variation in how this parameter is measured. Carbon Black plays a crucial role in UV protection for pipes, and deviation from the recommended value may impact the material's longevity in outdoor applications. The consistently low values reported by Lab-I warrant closer scrutiny to ensure their results fall within acceptable limits.
- Wall Thickness: Minimum and maximum wall thickness measurements showed relatively low variance. However, Lab I consistently reported the highest values. This uniformity in results across most laboratories suggests good precision in wall thickness measurements, but the deviations in Lab-I indicate potential over-specification of material usage. Upon analyzing the results from the ILC program, noticeable discrepancies were observed in the measurement of Melt Flow Rate (MFR) and Elongation at Break across the 11 participating laboratories. For MFR, the average value was 0.519 g/10min with a standard deviation of 0.064 g/10min. Laboratory H reported a significantly higher MFR of 0.623 g/10min, corresponding to a Z-score of 1.89, while Laboratory G measured a substantially lower MFR of 0.455 g/10min, resulting in a Z-score of -1.08. Similarly, for Elongation at Break, the overall average was 694.1%, with a standard deviation of 160.9%. Laboratory F recorded an exceptionally high elongation value of 1001%, yielding a Z-score of 1.90, whereas Laboratory E reported a notably low elongation of 329%, corresponding to a Z-score of -2.27. These statistical data highlight the variability in measuring MFR and Elongation at Break across different laboratories, underscoring the need for stricter standardization of testing conditions and equipment calibration.

6. Recommendations for Improvement

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

- Enhanced Quality Control: The PE pipe industry should invest in more standardized quality control measures across labs to minimize discrepancies in results for key parameters like Melt Flow Rate and Carbon Black content. This can be achieved through periodic proficiency testing and recalibration of instruments to ensure consistency.
- Innovative Testing Methods: Advanced non-destructive testing methods, such as ultrasonic wall thickness measurements, should be more widely adopted to

improve accuracy and reduce variability across manufacturers.

- Sustainability Focus: Manufacturers should focus on increasing the use of recycled materials in polyethylene pipes. Improved recycling techniques can maintain the mechanical properties of pipes, enhancing sustainability and reducing costs.
- Material Development: Investing in developing new PE formulations with better resistance to temperature extremes, chemical reactions, and UV radiation could significantly extend the lifespan of pipes in various environments.
- Digital Monitoring and Data Sharing: Implementing digital technologies to monitor pipe quality in real-time and data sharing between suppliers and users can lead to faster identification of faults and enhance overall product reliability.

7. Implications for the Pipe Industry

- Operational Efficiency: Improved quality control and testing methods will enhance operational efficiency by reducing product failures and the need for rework.
- Market Competitiveness: Companies investing in sustainability and innovative material development will be positioned as industry leaders, giving them a competitive edge.
- Regulatory Compliance: Adopting stricter control methods and testing will ensure compliance with international standards, fostering trust in global markets.

8. Training Methodologies for Laboratory Personnel

Training laboratory personnel is essential to ensure the accuracy and consistency of testing results. Training programs should cover the theoretical and practical aspects of testing polyethylene pipes according to IS 4984:2016. Theoretically, personnel should understand the significance of each test parameter, the testing principles, and the relevance to the performance of HDPE pipes in service. Personnel should be proficient in operating the testing equipment, preparing samples, conducting the tests, and interpreting the results.

Hands-on training and participation in interlaboratory comparison programs can be particularly beneficial. Additionally, laboratories should implement a quality management system that includes regular proficiency testing, equipment calibration, and documentation of results. Continuous training and professional development opportunities should be provided to laboratory personnel so they can stay updated with testing methodologies and standards advancements. By investing in laboratory personnel's competence, test results' reliability can be enhanced, contributing to the quality of HDPE pipes in the market.

9. Environmental Impact of HDPE Pipe Production

The production of High-Density Polyethylene (HDPE) pipes has several environmental implications that should be considered. The manufacturing process involves the extrusion of HDPE resin derived from petroleum resources. This contributes to greenhouse gas emissions and fossil fuel depletion. Additionally, the production process requires energy, often generated by burning fossil fuels and contributing to carbon emissions. However, HDPE pipes also offer environmental benefits in their application. They are durable and long-lasting, reducing the need for frequent replacements and the associated resource consumption. HDPE pipes also resist corrosion and scaling, minimizing water loss due to leakage. Furthermore, HDPE is recyclable at the end of its service life, allowing for the conservation of resources. Therefore, while HDPE pipe production has environmental impacts, the pipes provide several sustainability benefits in water supply systems.

10. Conclusion

The ILC provides a valuable overview of inter-laboratory consistency in testing Polyethylene Pipes. While most laboratories performed within acceptable bounds, outliers—especially in Elongation and Carbon Black content—highlight areas where labs might benefit from harmonizing methods and recalibrating equipment to ensure consistent results. Further investigation into the causes of significant deviations could improve overall testing reliability.

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Availability of Data and Materials

The data supporting the findings of this study are not publicly available to protect the privacy of laboratory participants. Requests for access to the data may be considered on a case-by-case basis, subject to approval by the relevant competent authority.

Contribution:

The corresponding author organized the ILC program and wrote the manuscript.

Abbreviations

PE: Polyethylene
MFR: Melt Flow Rate
HDPE: High-Density Polyethylene
IS: Indian Standard
UV: Ultraviolet
ISO: International Organization for Standardization
ILC: Inter-Laboratory Comparison

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Table 1. Lab Results and corresponding z-scores

Lab Code	Melt Flow Rate	Z-Score	Density	Z-Score	Elongation	Z-Score	Carbon Black	Z-Score	Wall Thickness (Min)	Z-Score	Wall Thickness (Max)	Z-Score
A	0.50	-0.30	955	1.19	550	-0.90	2.30	-0.47	3.78	-0.63	3.96	0.37
B	0.58	0.95	954	0.81	703	0.06	-	#VALUE!	3.79	-0.20	3.98	0.73
C	0.50	-0.30	950	-0.67	690	-0.03	2.40	0.01	3.78	-0.63	3.90	-0.73
D	0.50	-0.30	949	-1.04	720	0.16	2.30	-0.47	3.80	0.24	3.91	-0.55
E	0.47	-0.80	951	-0.30	329	-2.27	2.49	0.45	3.77	-1.07	3.96	0.37
F	0.62	1.57	957	1.93	1001	1.90	2.74	1.65	3.78	-0.63	3.85	-1.65
G	0.45	-1.08	951	-0.30	775	0.50	2.51	0.54	3.76	-1.50	3.98	0.73
H	0.64	1.89	952	0.07	700	0.04	2.63	1.12	3.82	1.11	4.00	1.10
I	0.47	-0.71	-	#VALUE!	748	0.33	2.10	-1.43	3.83	1.54	4.02	1.47
J	0.50	-0.30	949	-1.04	700	0.04	2.10	-1.43	3.81	0.67	3.88	-1.10
K	0.48	-0.61	950	-0.67	720	0.16	2.40	0.01	3.82	1.11	3.90	-0.73
Avg	**0.519**		**951.800**		**694.1**		**2.397**		**3.795**		**3.940**	
SD	**0.064**		**2.700**		**160.927**		**0.208**		**0.023**		**0.055**	

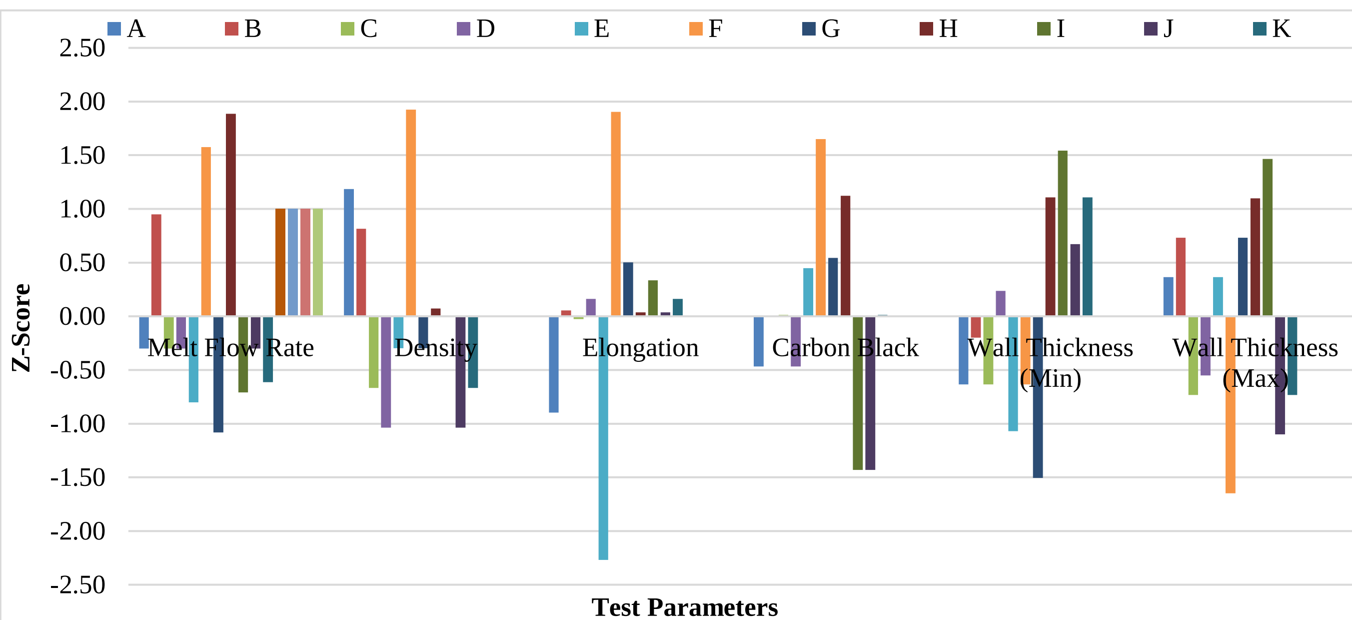

Fig. 1 Bar Chart showing the Z-Score against the test parameters