International Journal of Engineering Materials and Manufacture (2025) 10(3) 85-94
https://doi.org/10.26776/ijemm.10.03.2025.03

An Experimental Investigation of Mechanical Properties of uPVC Pipes Manufactured in Bangladesh

Md Ar Rafee Bin Akram, Samsul Islam, Md Mushfik Ul Islam, Md Shohidul Islam Masum and Mohammad Zoynal Abedin

Received: 21 June 2025
Accepted: 19 July 2025
Published: 31 July 2025
Publisher: Deer Hill Publications

ABSTRACT
With rapid urbanization, the demand for plastic-based infrastructure materials has increased significantly in Bangladesh over the past few decades. Currently, nearly eighty percent of pipes used for residential, commercial and industrial applications are manufactured locally. This study aims to assess the mechanical properties of domestically produced unplasticized polyvinyl chloride (uPVC) pipes and evaluate their compliance with international quality standards. Five specimens from different manufacturers were randomly selected and tested for Shore D hardness, impact resistance and tensile strength according to ASTM D2240, BS 3505 and ASTM D638 standards, respectively. The results revealed that forty percent of the specimens met both hardness and tensile strength requirements, while none of the specimens passed the impact resistance test. These findings highlight inconsistencies in the mechanical performance of locally manufactured uPVC pipes and suggest areas for quality improvement. The study provides essential insights for local manufacturers, regulators and consumers, contributing to the enhancement of product reliability and international competitiveness.
Keywords: Mechanical Properties, uPVC Pipe, Shore D Hardness, Impact Test, Tensile Strength, ASTM Standards.

NOMENCLATURE

Abbreviation / Symbol	Meaning
uPVC	Unplasticized Polyvinyl Chloride
ASTM	American Society for Testing and Materials
UTM	Universal Testing Machine
BS	British Standard
BSTI	Bangladesh Standards and Testing Institution
ASTM D638	Standard test method for tensile properties of plastics
ASTM D2240	Standard test method for hardness (Durometer Shore D)
BS 3505	British Standard for specification of uPVC pressure pipes
CH_2–CHCl	Polyvinyl Chloride monomer (MPa)
E	Modulus of elasticity
ν	Poisson's ratio
%	Percentage (elongation at break)
MPa	Megapascal (unit of stress/strength)
N/mm²	Newton per square millimeter

1 INTRODUCTION
The widespread use of uPVC pipes in water distribution systems, household plumbing and sewer infrastructures has led to a substantial increase in their demand across various sectors [1, 2]. In Bangladesh, the domestic plastic market has grown significantly, with an annual revenue of approximately USD 69 million, contributing to a total market valuation of around USD 950 million [3]. The consumption of plastics in the country is growing at an annual rate of

Md Ar Rafee Bin Akram[1], Samsul Islam[2], Md Mushfik Ul Islam[1], Md Shohidul Islam Masum[1] and Mohammad Zoynal Abedin[2]✉
[1]Department of Mechanical Engineering, Military Institute of Science and Technology, Dhaka 1216, Bangladesh.
[2]Department of Mechanical Engineering, Dhaka University of Engineering and Technology, Gazipur-1707, Bangladesh.
E-mail: abedin.mzoynal@duet.ac.bd

Reference: M. A. R. Akram, S. Islam, M. M. Islam, M. S. I. Masum, M. Z. Abedin (2025). An Experimental Investigation of Mechanical Properties of uPVC Pipes Manufactured in Bangladesh. *International Journal of Engineering Materials and Manufacture*, 10(3), 85-94.

16.2% [4]. According to this cheap, lightweight and corrosion-resistant material originally comes from Polyvinyl Chloride ($CH_2 - CHCl$) and is being used as a low-cost building material widely [5]. However, studies have confirmed that phthalates and bisphenol A (BPA) two toxic plasticizers are often added to PVC to enhance its flexibility [6, 7]. Thus, uPVC pipes have gained more popularity compared to PVC pipes over the years for their non-toxicity, even though they are hard and brittle in nature [8].

Moreover, due to their excellent UV resistance and mechanical stability, uPVC pipes are ideal for diverse out door applications [9]. Furthermore, Bangladesh is situated in a region vulnerable to earthquakes [10] and also used in earthquake-prone areas as part of an underground sewer systems, as heavy soil load doesn't significantly impact their performance provided there are no rocks nearby [11]. Therefore, compared to PVC pipes, uPVC pipes are a more suitable choice for domestic underground applications.

Bangladesh is home to a large number of plastic industries that provide support locally to the government-led development projects and also to the international buyers. Over the last 20 years, its manufacturing sector has experienced a significant expansion with around 5000 factories operating nationwide [12]. This growing industry has also contributed to the direct and indirect employment of 1.2 million people [13]. The locally manufactured products comply with the national standards formulated by BSTI. However, it remains unclear whether they meet international standards such as ASTM. Therefore, assessing the mechanical properties of these locally manufactured pipes has become essential.

While the government entities are the largest consumer of the pipes, the increasing purchasing power of the population has significantly fueled the overall demand. Until now, no comprehensive research has been conducted on locally manufactured uPVC pipes. Although a limited experiment was carried out in 2001 on a single PVC pipe sample. However, it doesn't reflect the conditions of currently available uPVC pipes, as over the years both technology and manufacturing process have advanced significantly. Testing random specimens from the market and comparing them with international standards will help consumers understand the ground reality of the product quality. This will build credibility and trust among both national and international customers.

To address this issue, this study aims to evaluate specimens from five different types of uPVC pipes collected from five leading manufacturers. Hardness, tensile and impact tests were conducted using a Shore D hardness durometer, a universal tensile testing machine and a drop-weight impact tester, respectively. The experimental data were later validated using international benchmarks under ASTM standards.

2 OBJECTIVES

The specific objectives of this study are:

i. To identify suitable experimental methods for determining the mechanical properties of locally manufactured uPVC pipe materials.
ii. To experimentally determine key mechanical properties hardness, impact resistance and tensile strength of different uPVC pipe specimens collected from various manufacturers.
iii. To compare the experimental results with relevant international standards such as ASTM D2240, BS 3505 and ASTM D638, and assess the compliance of local products.

3 METHODOLOGIES

The experimental procedures of this study were carried out in accordance with established international standards. Five types of locally manufactured uPVC pipe specimens were collected from different manufacturers. Mechanical properties were evaluated through standardized tests, including Shore D hardness (ASTM D2240), Falling Weight Impact Test (BS 3505), and tensile strength testing (ASTM D638). Specimens were prepared in accordance with the respective standards. Hardness was measured using a Shore D durometer, impact resistance was assessed by dropping a steel weight from a height of 2000 mm and tensile properties were determined using a 100 kN Universal Testing Machine. The obtained results were then compared against international benchmark standards.

3.1 Suitable methods of experiment to determine the mechanical properties of pipe material

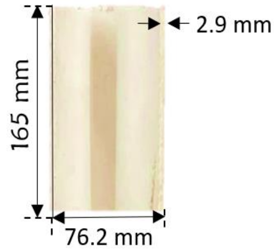
To assess the quality and performance of uPVC pipes, it is essential to determine their mechanical properties through standardized testing. ASTM D 638 specifies the methods to test the tensile strength of plastic and other resin materials, whereas ASTM D2240 is used to evaluate the hardness of various plastic materials. BS 3505 provides specifications for uPVC pipes. The specimens were shaped according to Type V geometry [14]. To identify the proper methods multiple books and research papers were studied thoroughly [15-19].

3.2 Determine different mechanical properties of the sample pipes

3.2.1 Hardness Test

Durometer is a device used to measure the hardness of various plastics and rubbers by determining the depth of an indentation created by a standardized presser foot under a specific force. The indentation depth depends on the material's hardness, viscoelastic properties, the presser foot's shape and the test duration. Durometers are commonly classified as Shore A and Shore D types.

(a) Shore D Durometer.



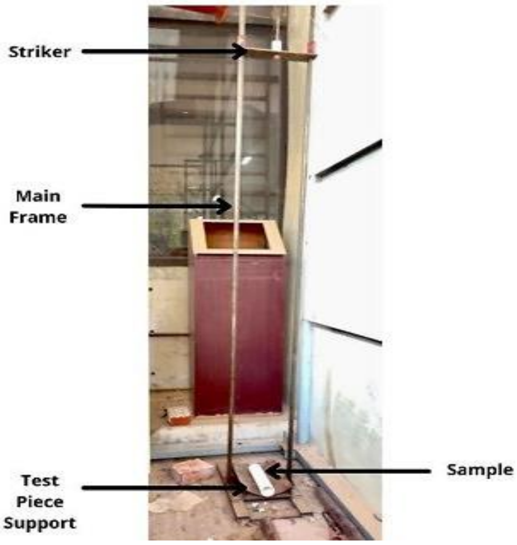
(b) Image of sample after the test.

Figure 1: Shore D hardness test set-up using ASTM D2240 durometer.

In this study, a Shore D durometer was used to measure surface hardness, as shown in Figure 1(a), while Figure 1(b) shows a sample after testing, with dimensions of 165 mm in length, 76.2 mm in diameter and 2.9 mm in wall thickness. Five samples were produced from each specimen, following ASTM D2240 standards for sample preparation. The Shore D hardness test was performed in accordance with the procedures described in [17, 20]. Each specimen was placed on a flat, hard, horizontal surface, and the durometer was calibrated before testing. The device was pressed firmly against the specimen and the reading was recorded once stabilized. This process was repeated for all specimens to ensure consistency and accuracy in the results.

3.2.2 Impact Test

Impact testing is used to assess a material's behavior under sudden shock loading, which may result in immediate deformation, fracture or rupture. While methods like the Charpy and Izod tests are common, this study employed the Falling Weight Impact Test following the BS 3505 standard. In this method, a specimen is placed in a fixture, and a known weight is released from a fixed height to strike the sample, transferring energy upon impact. This energy transfer reveals the material's fracture characteristics.



(a) Impact Tester.

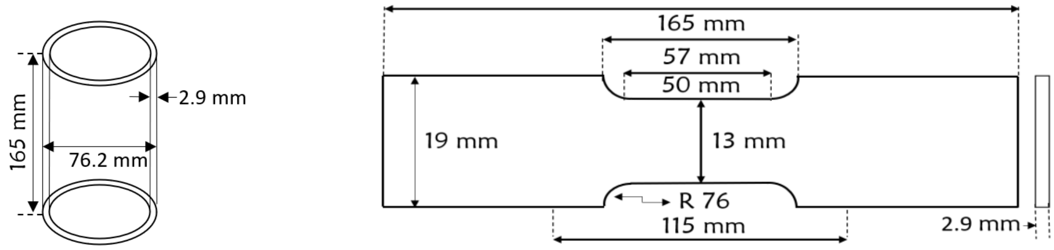
(b) Image of prepared test samples.

Figure 2: Drop weight impact test set-up for uPVC pipe samples (BS 3505 Standard).

Figure 2(a) shows the impact testing apparatus used, while Figure 2(b) presents five specimens prepared for testing. Sample preparation followed the "B2: Test Pieces" guidelines of the BS 3505 Handbook, with five specimens collected per sample group. The test procedure, based on BS 3505 Standard, involved raising a striker with a mass of 2.5 kg to a height of 2000 mm or 2.0 m and allowing it to fall freely under gravity (g = 9.81 m/s²) onto each specimen. The resulting impact energy (drop weight value=$mass \times gravity \times height$) was calculated as 49.05 joules [18]. Post-impact, specimens were inspected for cracks or deformations. The process was repeated for two additional specimens per group and if four consecutive specimens cracked, the material was classified as failed.

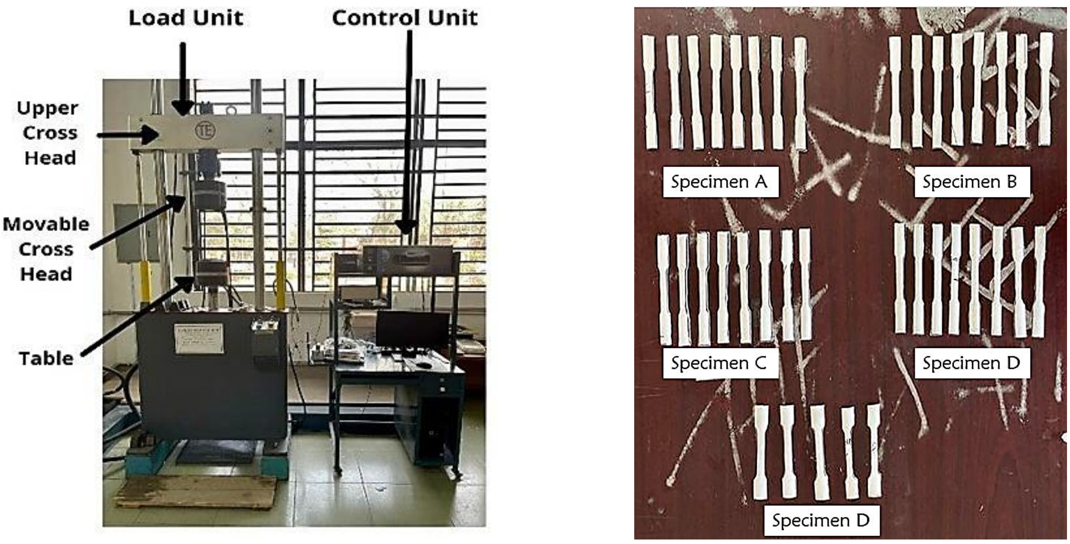
3.2.3 Tensile Strength

Tensile testing is a destructive method used to assess a material's response under controlled tensile loading until failure. It is performed to determine key mechanical properties such as yield strength, ultimate tensile strength, ductility, strain hardening behavior, Young's modulus, and Poisson's ratio. The test was conducted using an electro-hydraulic servo dynamic universal testing machine with a 100 kN load capacity, available at the applied mechanics laboratory, department of mechanical engineering, Military Institute of Science and Technology. Figure 3 illustrates the dimensions of the original uPVC pipe sample and the standardized tensile test specimen, prepared in accordance with ASTM D 638 for mechanical characterization.



(a) Pipe sample dimensions. (b) Dimensions of tensile test specimen.

Figure 3: Dimensions of (a) pipe sample and (b) tensile test specimen prepared according to ASTM D638 standard.



(a) Universal Testing Machine. (b) Image of the prepared test specimens A to D.

Figure 4: Universal testing machine set-up for tensile strength testing.

Figure 4(a) shows the Universal Testing Machine (UTM) used for the tensile tests, while Figure 4(b) displays the prepared test specimens labeled A to D. Each specimen was prepared with dimensions of 165 mm overall length, 57 mm gauge length, 19 mm grip section width, 13 mm narrow section width, 115 mm grip section length, 76 mm fillet radius (R) and 2.9 mm thickness. Specimen preparation followed the ASTM D638 standard, with five specimens collected from each of five sample groups, totaling 25 samples. Tensile testing and sample preparation were carried out on uPVC pipes according to the procedures outlined in [16, 21]. During testing, each specimen was clamped securely, and tensile load was applied via the control unit until the specimen fractured. Relevant data were recorded from the control unit, and the process was repeated for all samples to ensure consistency and reliability.

3.3 To compare the experimental values to the existing international standards

The experimental data following the above procedures were collected and studied to compare them with international standards such as ASTM D2240, BS 3505 and ASTM D638 [23,24].

4 DATA AND CALCULATIONS

4.1 Hardness Test

The hardness test was performed using a Shore D durometer, and the experimental data obtained for five different uPVC specimens which are labeled A to E are presented in Table 1. For each specimen, five samples were tested with three readings recorded per sample to determine the average value. The mean average hardness values for each specimen group were then calculated.

Table 1: Experimental data of the shore d hardness of specimen A to E.

Specimen	Sample	Observation-1	Observation -2	Observation -3	Average	Mean Avg.
A	1	70	74	70	71.33	68.73
	2	60	70	78	69.33	
	3	65	56	74	65.00	
	4	63	70	69	67.33	
	5	74	71	67	70.67	
B	1	63	78	73	71.33	69.00
	2	62	77	69	69.33	
	3	67	72	71	70.00	
	4	64	70	72	68.67	
	5	65	63	69	65.67	
C	1	50	55	58	54.33	56.27
	2	61	55	60	58.67	
	3	55	58	57	56.67	
	4	52	57	56	55.00	
	5	58	56	56	56.67	
D	1	60	64	62	62.00	66.13
	2	70	69	69	69.33	
	3	65	66	66	65.67	
	4	69	62	66	65.67	
	5	72	65	67	68.00	
E	1	70	72	72	71.33	69.93
	2	69	72	71	70.67	
	3	66	68	69	67.67	
	4	67	70	71	69.33	
	5	72	70	70	70.67	

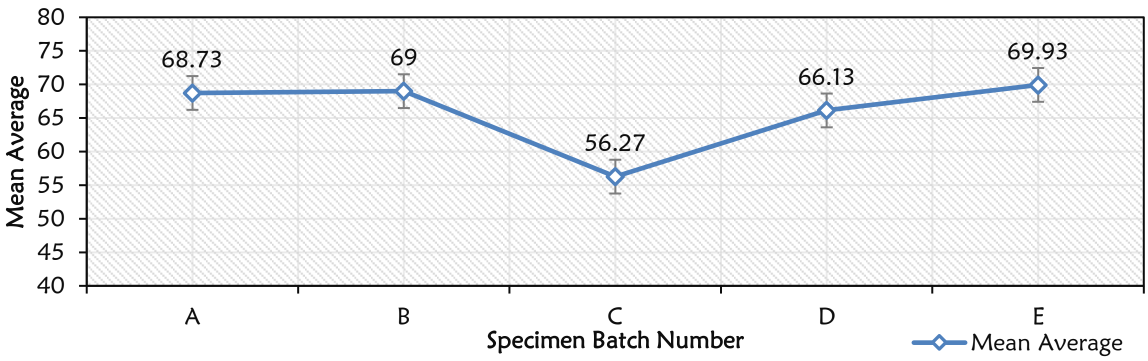


Figure 5: Mean average shore d hardness values of specimen batch number A to E.

Table 1 illustrates the detailed Shore D hardness values, individual sample averages, and the overall mean average for each specimen group. Among the specimens, specimen E exhibited the highest mean average hardness value of 69.93, followed closely by 69 for specimen B and 68.73 for specimen A. The values for specimens A, B and D remained relatively consistent, falling within the 66 to 69 range. In contrast, specimen C showed the lowest mean average value at 56.27, indicating relatively lower hardness performance compared to the others.

The graphical illustration in Figure 5 clearly reflects this variation, supporting the tabulated data, where the mean average Shore D hardness values for each specimen group are plotted. The graphical trend highlights the comparative hardness levels, with specimen E maintaining a consistently higher value and specimen C significantly lower.

4.2 Impact Test

The impact resistance of the uPVC specimens was evaluated through a drop weight impact test, conducted as per BS 3505 standards. In this test, five specimens A to E were each subjected to four consecutive impact observations to assess their ability to withstand sudden shock loading.

Table 2: Experimental data of impact test of specimen A to E.

Specimen	Sample	Observation-1	Observation-2	Observation-3	Observation-4
A	1	Fail	Fail	Fail	Fail
	2	Fail	Fail	Fail	Fail
	3	Fail	Fail	Fail	Fail
	4	Fail	Fail	Fail	Fail
	5	Fail	Fail	Fail	Fail
B	1	Fail	Fail	Fail	Fail
	2	Fail	Fail	Fail	Fail
	3	Fail	Fail	Fail	Fail
	4	Fail	Fail	Fail	Fail
	5	Fail	Fail	Fail	Fail
C	1	Fail	Fail	Fail	Fail
	2	Fail	Fail	Fail	Fail
	3	Fail	Fail	Fail	Fail
	4	Fail	Fail	Fail	Fail
	5	Fail	Fail	Fail	Fail
D	1	Fail	Fail	Fail	Fail
	2	Fail	Fail	Fail	Fail
	3	Fail	Fail	Fail	Fail
	4	Fail	Fail	Fail	Fail
	5	Fail	Fail	Fail	Fail
E	1	Fail	Fail	Fail	Fail
	2	Pass	Fail	Fail	Fail
	3	Fail	Fail	Fail	Fail
	4	Fail	Fail	Fail	Fail
	5	Fail	Fail	Fail	Fail

Table 2 presents the detailed results of the impact test for each specimen group. The data reveal a consistent failure pattern across all specimens, with every sample from specimens A, B, C and D failing in all four observations. Only sample 2 in specimen E showed a single instance of resistance by passing the first observation, before failing in the subsequent three trials. The overall results suggest that the uPVC specimens tested possess low impact resistance under the applied conditions of this study. According to BS 3505, the threshold of failure for the drop weight impact test is reached when four consecutive specimens from the same batch fail under the specified test conditions. If this occurs, the entire batch is considered non-compliant with the standard's impact resistance requirements. In this study, all specimen groups exceeded this threshold, indicating inadequate impact performance.

4.3 Tensile Strength

The tensile behavior of the uPVC specimens was examined through a comprehensive tensile test, focusing on four key mechanical properties: tensile strength at break, elongation at break, tensile modulus and yield strength. Each specimen group (A to E) was tested across five samples under identical conditions. The evaluation was performed to determine the material's mechanical integrity, ductility and load-bearing capacity. Table 3 presents the detailed tensile test results of all specimens, while Figures 6 to 10 graphically illustrate the variation in each mechanical property across the samples for individual specimen groups.

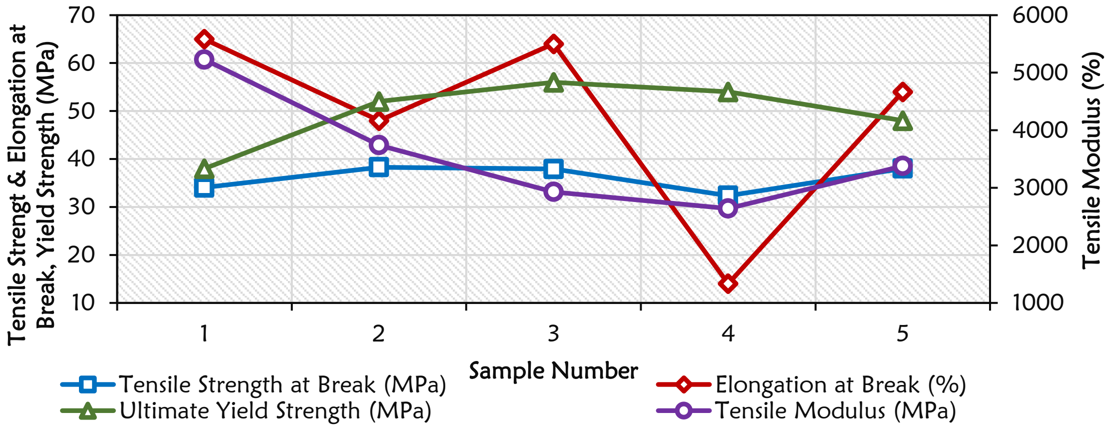


Figure 6: Experimental data of the tensile strength of specimen A, sample 1 to 5.

Table 3: Experimental data of mechanical properties of specimens A to E from sample 1 to 5.

Specimen	Elements of Mechanical Properties	Sample-1	Sample -2	Sample-3	Sample-4	Sample-5
A	Tensile Strength at Break (MPa)	34.05	38.28	37.93	32.36	38.04
	Elongation at Break (%)	65	48	64	14	54
	Tensile Modulus (MPa)	5230	3740	2930	2640	3380
	Yield Strength (MPa)	38	52	56	54	48
B	Tensile Strength at Break (MPa)	23	32.27	37.95	35.06	42.07
	Elongation at Break (%)	66	62	64	64	64
	Tensile Modulus (MPa)	2920	2490	2930	2705	2710
	Yield Strength (MPa)	35	31.25	35	33	39
C	Tensile Strength at Break (MPa)	43.56	57.42	45.54	50.49	51.48
	Elongation at Break (%)	36	48	52	42	46
	Tensile Modulus (MPa)	3330	3740	3600	3320	3989
	Yield Strength (MPa)	40	46	42	43	43
D	Tensile Strength at Break (MPa)	34	32.36	36.76	33.18	34.97
	Elongation at Break (%)	83	14	14	48	31
	Tensile Modulus (MPa)	3010	2640	3050	2825	2937
	Yield Strength (MPa)	35	34	34	34	31.36
E	Tensile Strength at Break (MPa)	42.48	35.88	39.34	41.07	40.2
	Elongation at Break (%)	54	69	54	58	60
	Tensile Modulus (MPa)	3380	3110	3380	3312	3287
	Yield Strength (MPa)	42	40	41	42	41

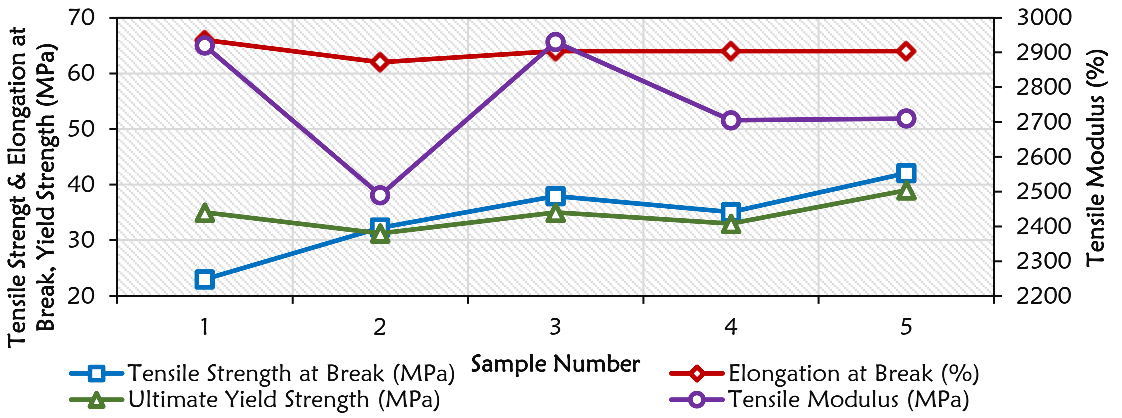


Figure 7: Experimental data of the tensile strength of specimen B, sample 1 to 5.

From Figure 6, it is observed that the tensile strength at break fluctuates slightly, with values ranging between 32.36 MPa and 38.28 MPa. The elongation at break shows considerable variation, particularly at 14% for sample 4, which is significantly lower than others, such as 65% for sample 1. The tensile modulus follows a declining trend from 5230 MPa in sample 1 to 2640 MPa in sample 4, indicating reduced stiffness. Despite this, the yield strength remains relatively high, peaking at 56 MPa in sample 3.

As shown in Figure 7, specimen B presents a gradual increase in tensile strength from 23 MPa in sample 1 to 42.07 MPa in sample 5. Elongation remains relatively stable between 62 to 66%, suggesting consistent ductility. The tensile modulus displays minor variation, ranging between 2490 MPa and 2930 MPa. The yield strength fluctuates slightly but increases towards the final sample 39 MPa, indicating slight strengthening over the samples.

Figure 8 illustrates that specimen C consistently yields the highest tensile strength values, peaking at 57.42 MPa in sample 2. The elongation at break varies moderately between 36 to 52%, indicating a balance between ductility and toughness. The tensile modulus is also notably higher compared to specimens B and D, with a maximum of 3989 MPa. The yield strength remains consistently high across all samples around 40 to 46 MPa, confirming strong mechanical integrity.

Figure 9 highlights that specimen D shows the lowest and most inconsistent elongation at break values, notably dropping to just 14% in samples 2 and 3. The tensile strength at break ranges between 32.36 MPa and 36.76 MPa, and the tensile modulus varies moderately around 2640 to 3050 MPa. The yield strength remains constant at around 34 to 35 MPa, except for a slight decline in sample 5 around 31.36 MPa. This indicates a reduction in ductility while maintaining moderate strength.

According to Figure 10, specimen E exhibits relatively stable mechanical behavior. The tensile strength at break ranges from 35.88 to 42.48 MPa, and elongation at break shows good ductility, peaking at 69% in sample 2. The tensile modulus also remains steady, fluctuating slightly around 3110 to 3380 MPa. The yield strength is consistently around 40 to 42 MPa across all samples, indicating excellent repeatability and reliability in mechanical performance. Among all specimens, specimen C demonstrates superior tensile strength and modulus, suggesting it is the most robust under stress. Specimen D, on the other hand, has the lowest ductility and comparatively inconsistent performance. Specimen E shows a balanced mechanical profile with consistent strength and ductility, making it a promising material candidate.

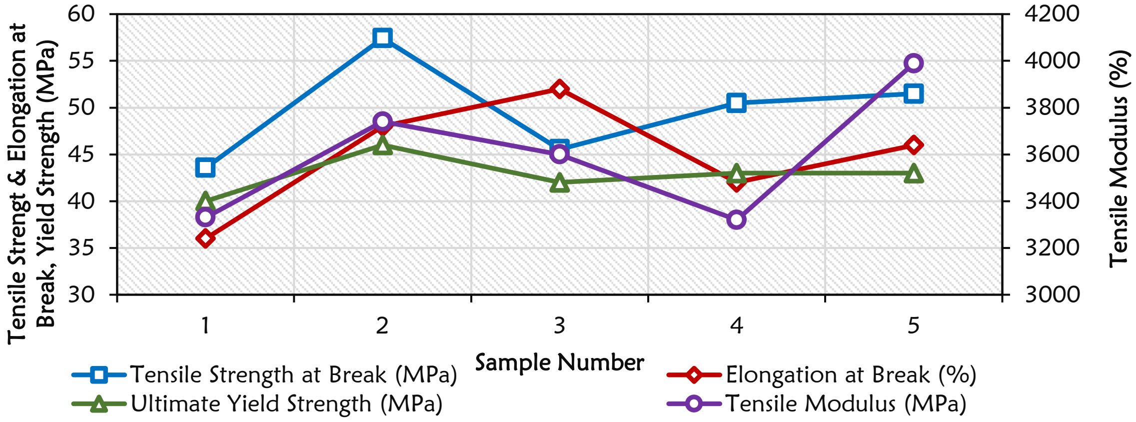


Figure 8: Experimental data of the tensile strength of specimen C, sample 1 to 5.

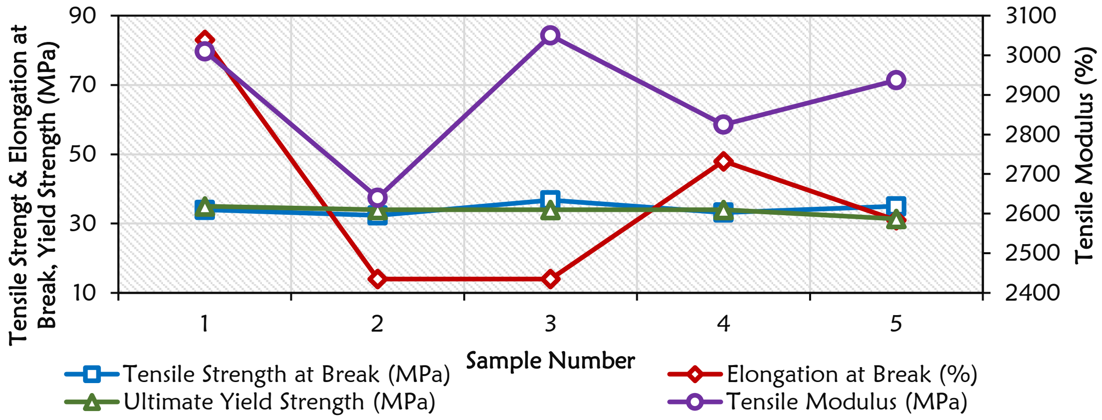


Figure 9: Experimental data of the tensile strength of specimen D, sample 1 to 5.

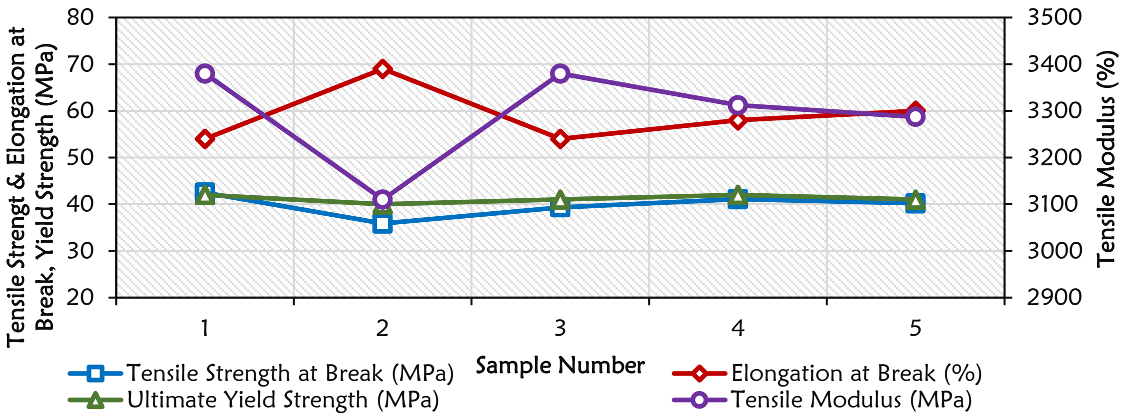


Figure 10: Experimental data of the tensile strength of specimen E, sample 1 to 5.

5 RESULTS AND DISCUSSION

Based on the experimental investigation into the mechanical performance characteristics of five uPVC pipe specimens A to E and the average Shore D hardness values were found to be 68.73 for specimen A, 69.00 for specimen B, 56.27 for specimen C, 66.13 for specimen D and 69.93 for specimen E. According to ASTM D2240, the acceptable Shore D hardness range for uPVC pipe materials typically spans from 65 to 90. Thus, specimens A, B, D and E satisfy the minimum hardness requirement, while specimen C falls below the threshold, indicating potential material inconsistency or insufficient curing during manufacturing. As well impact testing conducted in accordance with BS 3505 standards, revealed a consistent failure trend across the specimens. All specimens from batches A to D failed consistently in all four drop-weight observations but specimen E showed marginal resistance where sample 2 passed the first drop but failed in subsequent trials. Additionally, as per BS 3505 criteria a batch is deemed non-compliant if four consecutive failures occur. Therefore, none of the specimen groups met the impact resistance requirement, highlighting a critical deficiency in impact durability across locally produced uPVC pipes.

On the other hand, the tensile test results further differentiated the mechanical quality of the specimens and the average tensile strength at break was 36.13 MPa for specimen A, 34.07 MPa for specimen B, 49.70 MPa for specimen C, 34.25 MPa for specimen D and 39.79 MPa for specimen E. These results suggest that specimens A, C and E are within or above the ASTM D638 acceptable range, whereas specimens B and D fall slightly below the minimum requirement. Whereas the average percentage of elongation at break, an indicator of ductility, showed considerable variation was 49% for specimen A, 64% for specimen B, 44.8% for specimen C, 38% for specimen D and 59% for specimen E. Specimen B exceeded typical elongation limits, while the others remained within acceptable boundaries. Furthermore, the average tensile modulus values were calculated as 3584 MPa for specimen A, 2751 MPa for specimen B, 3595.8 MPa for specimen C, 2892.4 MPa for specimen D and 3293.8 MPa for specimen E. These values reflect material stiffness, with specimen C exhibiting the highest modulus, implying superior load resistance. Finally, the average tensile strength at yield was found to be 49.6 MPa for specimen A, 34.65 MPa for specimen B, 42.80 MPa for specimen C, 33.67 MPa for specimen D and 41.2 MPa for specimen E. Consequently, it can be inferred that specimen A, specimen C and specimen E are within the standard limit while specimen B and specimen D are below the minimum limit for tensile Strength at break. Overall, specimen C demonstrated the most balanced mechanical performance, combining high strength, adequate ductility and stiffness although it failed in hardness. In contrast, specimen B exhibited acceptable ductility but lacked sufficient strength and hardness. These findings emphasize the variation in quality among locally manufactured uPVC pipes and suggest the need for process improvements and tighter quality control.

6 CONCLUSIONS

Based on the mechanical performance assessment of five types of locally manufactured uPVC pipe specimens, the major findings of this study are summarized as follows:

i. Approximately 40% of the tested specimens fulfilled both Shore D hardness and tensile strength requirements specified in ASTM D2240 and ASTM D638 standards, while the remaining 60% met at least one criterion but failed to fulfill others.
ii. Specimens C and E failed to meet the minimum Shore D hardness value of 65 under ASTM D2240, recording average hardness values of 56.27 and 69.93 respectively, highlighting variability in material consistency across the tested samples.
iii. Specimens B and D failed to meet the ASTM D638 minimum required tensile strength at yield, with average values of 34.07 MPa and 33.67 MPa respectively, indicating potential weaknesses in certain product batches due to substandard resin composition or processing errors.
iv. None of the specimens passed the BS 3505 drop weight impact test, revealing a significant limitation in the impact durability of the tested uPVC pipes in real-world applications, especially in underground installations prone to sudden loads, suggesting an urgent need for manufacturers to enhance impact resistance in production processes.
v. All specimens except specimen B exhibited elongation at break within the acceptable range with specimen B exceeding the maximum limit, indicating inconsistency in ductility and strain response among different specimens.
vi. The findings indicate areas for quality improvement, particularly in impact performance and tensile strength consistency and manufacturers should prioritize optimizing material formulation, processing conditions and quality control measures to meet international standards more consistently.
vii. Future research may investigate additional mechanical properties, analyze the effects of chemical composition variations inconsistent behavior among specimens and evaluate the performance of uPVC pipes under diverse thermal and environmental conditions.

ACKNOWLEDGEMENTS

The authors would like to take the opportunity to acknowledge Dr. Md. Quamrul Islam, late Professor, Department of Mechanical Engineering, Military Institute of Science and Technology (MIST), Dhaka-1216, Bangladesh, for supervising the present experimental work. The authors also gratefully acknowledge the laboratory staff of the

Department of Mechanical Engineering, Military Institute of Science and Technology (MIST), Dhaka-1216, Bangladesh, for their technical support and cooperation in conducting the experimental work for this study.

REFERENCES

[1] Al-Malack, M. H., & Sheikheldin, S. Y. (2001). Effect of solar radiation on the migration of vinyl chloride monomer from unplasticized PVC pipes. Water research, 35(14), 3283-3290.
[2] Makris, K. F., Langeveld, J., & Clemens, F. H. (2020). A review on the durability of PVC sewer pipes: research vs. practice. Structure and Infrastructure Engineering, 16(6), 880-897.
[3] Islam, M. S. (2011). Prospects and challenges of plastic industries in Bangladesh. Journal of Chemical engineering, 26, 16-21.
[4] Haque, S. E., & Chowdhury, N. N. (2025). Bangladesh Plastic Consumption Trend: Current Scenario. Water, Air, & Soil Pollution, 236(4), 1-24.
[5] Martins, J. D. N., Freire, E., & Hemadipour, H. (2009). Applications and market of PVC for piping industry. Polímeros, 19, 58-62.
[6] Heudorf, U., Mersch-Sundermann, V., & Angerer, J. (2007). Phthalates: toxicology and exposure. International journal of hygiene and environmental health, 210(5), 623-634.
[7] Lopez-Cervantes, J., & Paseiro-Losada, P. (2003). Determination of bisphenol A in, and its migration from, PVC stretch film used for food packaging. Food Additives & Contaminants, 20(6), 596-606.
[8] Alahapperuma, K. G., & Samarasekara, A. M. P. B. (2019). Degradation of 94exicana94ized poly vinyl chloride-based engineering products upon exposure to ultra violet radiation. Tropical Agricultural Research, 30(4).
[9] Zhang, H. (Ed.). (2011). Building materials in civil engineering. Elsevier.
[10] Rahman, N., Ansary, M. A., & Islam, I. (2015). GIS based mapping of vulnerability to earthquake and fire hazard in Dhaka city, Bangladesh. International journal of disaster risk reduction, 13, 291-300.
[11] Alzabeebee, S. (2019). Response of buried uPVC pipes subjected to earthquake shake. Innovative Infrastructure Solutions, 4(1), 52.
[12] Majumder, T. A., Nur, S. S., & Haque, A. (2018). A Study on Characteristics of Small-Scale Plastic Industries in Dhaka North and South City Corporations. Journal of Bangladesh Institute of Planners, 89-105.
[13] Islam, M. S., Hasan, M. M., & Hossain, M. M. (2017). Current status of plastic production, prospects and training of manpower in Bangladesh. Journal of Chemical Engineering, 30(1), 69-76.
[14] Xiao, X. (2008). Dynamic tensile testing of plastic materials. Polymer testing, 27(2), 164-178.
[15] ASTM Committee D-20 on Plastics. A.S.T.M. Standards on Plastics: Specifications, Methods of Testing, Nomenclature, Definitions. The Society, Philadelphia, PA, 1945. Digitized by The Ohio State University, April 30, 2025.
[16] ASTM International. ASTM D638-14: Standard Test Method for Tensile Properties of Plastics. https: //www.astm.org/D0638-14.html, 2014. Standard Specification. [Access on 10 Jun, 2025]
[17] ASTM International. ASTM D2240-15e1: Standard Test Method for Rubber Property—Durometer Hardness. https://www.astm.org/D2240-15E1.html, 2015. Standard Specification. [Access on 10 Jun, 2025]
[18] British Standards Institution. BS 3505:1968 – Specification for unplasticized PVC pipe for cold water services, 1968. Standard.
[19] Mandal A. C. & Islam M. Q. (1999). Mechanics of Materials Laboratory Practice. Bangladesh University of Engineering & Technology, Dhaka, Bangladesh.
[20] Zisopol, D. G., Minescu, M., Iacob, D. V., & Voicu, N. (2024). Study of the Tensile Strength and Shore Hardness Behavior of PE100 SDR11 Electrofusion Welded and Artificially aged Pipes. Engineering, Technology & Applied Science Research, 14(3), 14566-14571.
[21] Huerta, E., Corona, J. E., Oliva, A. I., Avilés, F., & González-Hernández, J. (2010). Universal testing machine for mechanical properties of thin materials. Revista 94exicana de física, 56(4), 317-322.
[22] Gathimba, N. K. (2015). Performance of UPVC pipe confined concrete columns in compression (Doctoral dissertation).
[23] Raza, A., Mushtaq, A., & Saleem, A. (2024). Effect of Modified Waste Bio-Filler for Sustainable Reinforced Polymer Composite for a Circular Economy. Iran. J. Chem. Chem. Eng. (IJCCE) Research Article Vol, 43(9).
[24] Lanham, B. J., & Titow, W. V. (1984). Rigid PVC: Main Products Production, Properties and Applications. In PVC Technology (pp. 849-900). Dordrecht: Springer Netherlands.