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Evaluation of the Long-Term Hydrostatic Pressure Resistance of PPR and PVC Pipes

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Abstract— *industrial applications, evaluating long-term performance under sustained pressure has become essential. This study aims to assess and compare the long-term hydrostatic pressure resistance of Polypropylene Random Copolymer (PPR) and Polyvinyl Chloride (PVC) pipes at various temperatures. Stress Rupture Testing was conducted according to standard procedures, where pipe specimens were exposed to constant internal pressure at 30°C, 35°C, and 40°C. The hoop stress (S) was determined using the relation* $= \frac{P(D-t)}{2t}$ *. Results showed that PPR pipes exhibit superior hydrostatic pressure resistance compared to PVC under identical conditions, confirming their suitability for water supply systems. Additionally, the inclusion of recycled material was found to reduce the long-term lifespan of both materials. These findings contribute to estimating the Hydrostatic Design Basis (HDB) and enhancing the reliability of thermoplastic pipe application*

Keywords: PPR Pipes, PVC Pipes, Hydrostatic Pressure Test, Stress Rupture, Hoop Stress, Long-Term Lifespan.

1. INTRODUCTION

Plastic pipes, particularly those made from Polypropylene Random Copolymer (PPR) and Polyvinyl Chloride (PVC), are essential components in water supply networks and HVAC systems worldwide. The long-term performance of these pipes critically depends on their ability to withstand internal stresses resulting from fluid pressure and temperature. Unlike metals, the long-term strength of plastic materials cannot be determined from short-term tensile strength tests, necessitating the development of specialized evaluation methodologies that account for the material's stress-rupture response over extended periods. The common method for forecasting long-term strength relies on subjecting specimens to multiple continuous stress levels until failure. This data is then used in a log-log linear regression evaluation, and the resulting equation is extrapolated to a point sufficiently far out in time to forecast the long-term strength. It has been established that failure acceleration can be significantly achieved by elevating the testing temperature, as this acceleration follows an Arrhenius, or rate process, behavior common to many chemical and mechanical processes. However, some thermoplastics like PVC do not lend themselves to these accelerated methodologies as they may change phase at elevated temperatures, rendering the test unrepresentative of the original material properties. Previous research has highlighted the importance of stress rupture testing in assessing the lifespan of plastic pipes. Farshad (2005) [1] presented a new methodology for predicting the long-term creep rupture behavior of multilayer pipes under internal hydrostatic pressure. Litvinov (2005) [2] studied the effect of storing polypropylene pipes under hydrostatic pressure and elevated temperatures on morphology, molecular mobility, and failure behavior. Krishnaswamy (2005) [3] analyzed ductile and brittle failures from creep rupture testing of high-density polyethylene (HDPE) pipes. In another study, Farshad (2007) [4] evaluated the long-term hydrostatic resistance of multilayer pipes using a combined quadratic/linear regression analysis. Boros (2011) [5] emphasized the basic methodology used to establish the long-term hydrostatic strength of thermoplastic piping compounds. Laiarinandrasana et al. (2011) [6] addressed the effects of aging on the creep behavior and residual lifetime assessment of Polyvinyl Chloride (PVC) pipes. Poduška et al. (2014) [7] investigated the residual stress distribution in extruded polypropylene pipes and its effect on fracture behavior. In a related context, Rafiee and Mazhari (2016) [8] simulated long-term hydrostatic pressure tests on glass fiber reinforced plastic pipes. Geertz et al. (2017) [9] studied the effect of long-term hydrostatic pressure on PPR pipes to analyze antioxidant diffusion. Ouardi et al. (2019) [10] conducted a comparative study of the severity of circumferential and axial defects on the failure of Polypropylene Random Copolymer (PPR) pipes. In a comprehensive review, Makris (2020) [11] discussed the main factors and mechanisms affecting the lifetime of PVC pipes. He (2021) [12] provided a theoretical stress and failure analysis for thermoplastic composite pipes under thermomechanical loading. More recently, Ouardi (2022) [13] studied the effect of residual stresses on the fracture of polypropylene pipes. Espejo (2023) [14] analyzed the failure of a PVC pipe due to creep deformation and slow crack growth (SCG). Finally, Deveci et al. (2024) [15] performed creep rupture tests on plastic pipes to study the effect of eccentricity, residual stress, and circumferential orientation. Collectively, these studies underscore the importance of accelerated testing and accurate lifespan prediction to ensure the safety and reliability of plastic piping systems.

2. EXPERIMENTAL METHODOLOGY

2.1. Test Method

This test method involves exposing pipe specimens to a constant internal pressure while in a controlled environment, such as a controlled temperature water or air bath. The time-to-failure is measured. Dimensional changes should also be measured on

specimens undergoing long-term strength tests, with measurements using circumferential tapes, strain gauges, or mechanical extensometers providing useful information.

2.2. Test Specimens

Pipe Specimen Length:

- For pipe sizes of 6 in. (150 mm) or less: The specimen length between end closures shall be not less than five times the nominal outside diameter of the pipe, but in no case less than 12 in. (300 mm). The 12 in. (300 mm) minimum specimen length requirement shall not apply to molded specimens.
- For larger sizes of pipe: The minimum length between end closures shall be not less than three times the nominal outside diameter but in no case less than 30 in (760 mm).

2.3. Conditioning

- At 23°C: Specimens shall be conditioned at test temperatures in a liquid bath for a minimum of 1 hour or in a gaseous medium for a minimum of 16 hours before pressurizing.
- At higher temperatures: Condition them in the elevated temperature environment until they have reached the test temperature.

2.4. Test Equipment

The basic test equipment consists of:

1 Constant-Temperature System: To control the test environment.
2 Pressurizing System: To apply internal pressure.
3 Pressure Gage: To measure the applied pressure.
4 Timing Device: To measure the time-to-failure.
5 Specimen End Closures: To seal the ends of the specimen.
6 Time and Pressure Tolerance.

All the above components, with some additional features, can be acquired as assembled stress rupture testers. Some units utilize a liquid bath environment that can be adjusted from −20 to +150°C. Other units offer a single pressure source with as many as 40 manifolds that can each be set for a different pressure and 240 specimen positions.

2.5. Procedure

7 Preparation: Attach end closures to the pipe test sections and fill each specimen completely with the test fluid conditioned to the test temperature. Attach the specimens to the pressuring device, making certain no gas is entrapped when using liquids. Completely immerse the test specimens in the conditioning medium.
8 Support: Support specimens in such a way as to prevent bending or deflection by the weight of the pipe while under test. This support shall not constrain the specimen circumferentially or longitudinally.
9 Pressure Application: After conditioning the specimens, adjust the pressure to produce the desired loading. Apply the pressure to the specimens and make sure the timing devices have started.
10 Recording Time-to-Failure: Record the time-to-failure of each specimen. The time-to-failure shall not include periods of time during which the specimen was under depleted pressure or under no pressure.
11 Failure Examination: Any failure occurring within one pipe diameter of the end closure shall be examined carefully. If there is any reason to believe that the failure is attributable to the end closure, the value shall be discarded in computing averages or in plotting the data.
12 Exclusion of Failure: The failure value of a specimen that fails due to column buckling shall be discarded in computing averages or in plotting the data.
13 Pressure Connections: Each specimen may be pressured individually or through a manifold system. If a manifold system is utilized, each pressure connection should include a check valve to prevent pressure depletion of the system when one specimen fails.

2.6. Test Fluids

While water is normally used inside the test specimens, any fluid may be used. However, if a gas is used, special care must be taken because of the potential energy stored in any compressed gas.

3. CALCULATIONS AND RESULTS

3.1. Hoop Stress Calculation

The hoop stress (S) in the pipe specimens is calculated using the following approximation equation:

$$S = \frac{P(D - t)}{2t}$$

Where:

- S: Hoop stress, in Megapascals (Mpa).
- P: Internal pressure, in Megapascals (Mpa).
- D: Average outside diameter, in millimeters (mm).
- t: Minimum wall thickness, in millimeters (mm).

3.2. PVC Pipe Results at 30°C

Specimen	Outside Diameter D (mm)	Wall Thickness t (mm)	Pressure P(Mpa)	Hoop Stress S(Mpa)	Time (s)
1	33	2.9	3	15.56	3
2	33	2.9	3	15.56	3
3	33	2.9	2	10.72	5
4	33	2.9	1	5.36	6
5	33	2.9	3	15.56	6

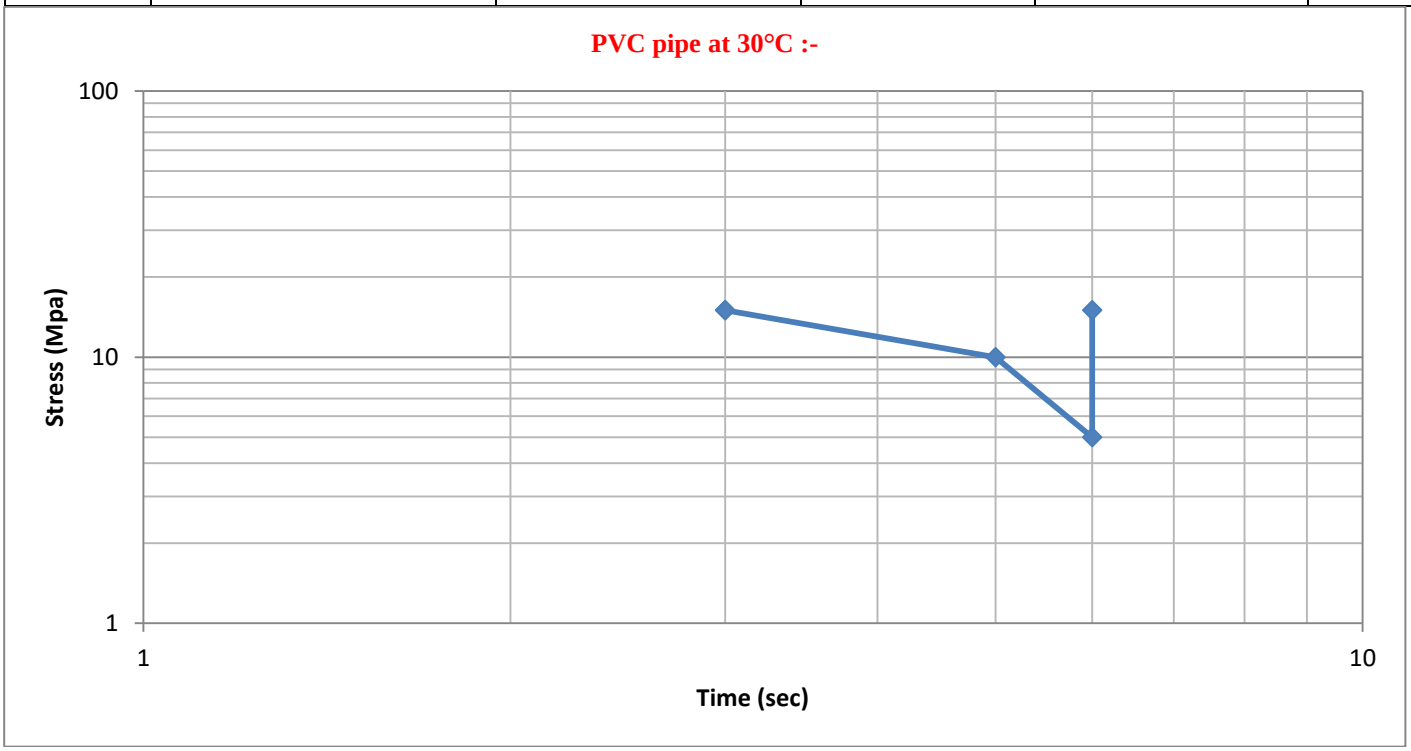

Figure 1: Stress-Rupture Curve for PVC Pipe at 30°C

Note: Hoop stress values were calculated based on the provided data.

3.3. PVC Pipe Results at 35°C

Specimen	Outside Diameter D(mm)	Wall Thickness t(mm)	Pressure P (Mpa)	Hoop Stress S(Mpa)	Time t (s)
1	33	2.9	3	15.56	4
2	33	2.9	2	10.72	5
3	33	2.9	2	10.72	5
4	33	2.9	3	15.56	5
5	33	2.9	1	5.36	7

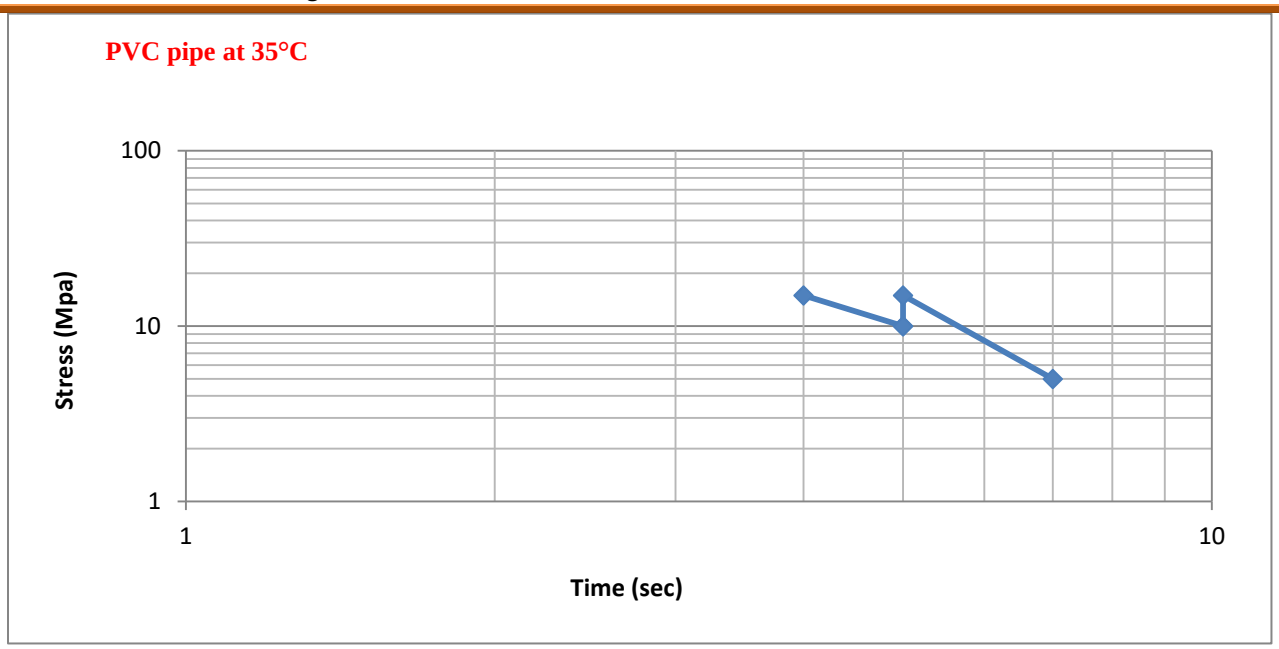

Figure 2: Stress-Rupture Curve for PVC Pipe at 35°C

3.4. PVC Pipe Results at 40°C

Specimen	Outside Diameter D (mm)	Wall Thickness t (mm)	Pressure P (Mpa)	Hoop Stress S (Mpa)	Time t(s)
1	33	2.9	2	10.72	3
2	33	2.9	3	15.56	3
3	33	2.9	3	15.56	3
4	33	2.9	2	10.72	4
5	33	2.9	2	10.72	5

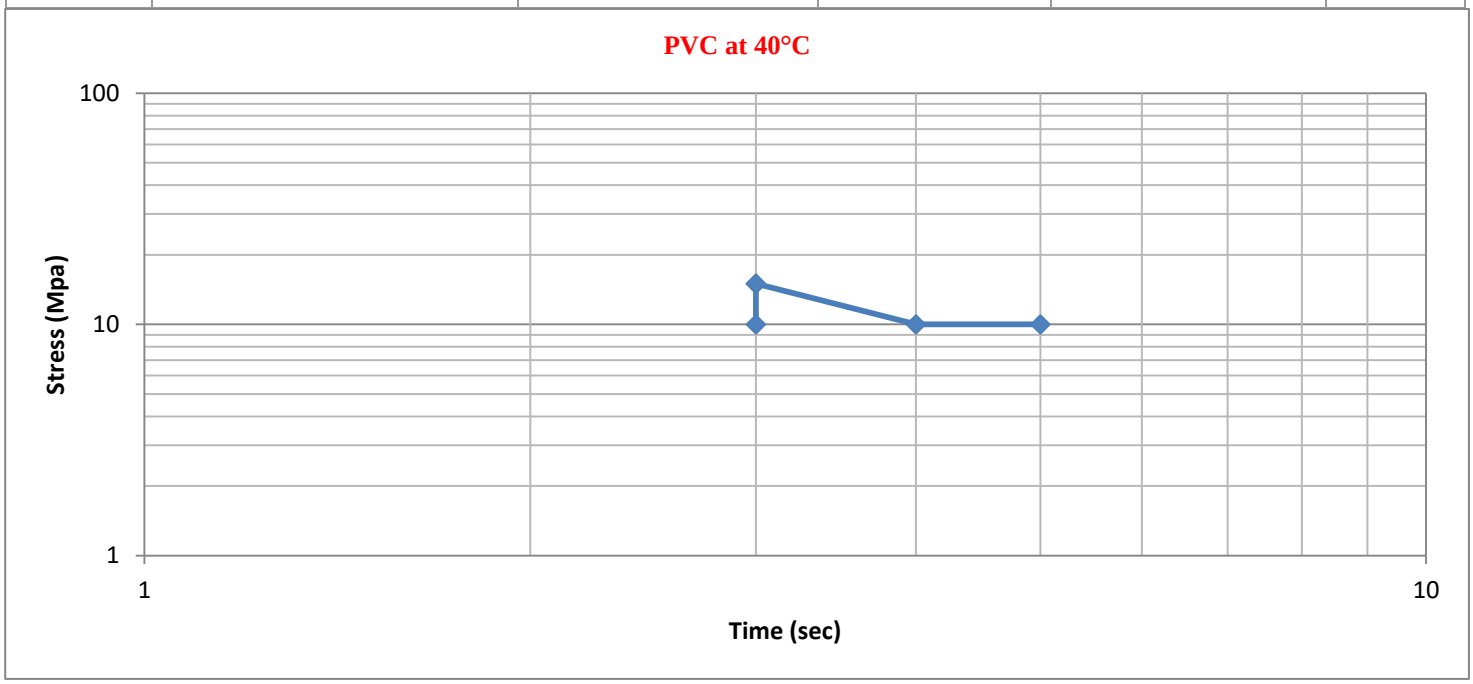

Figure 3: Stress-Rupture Curve for PVC Pipe at 40°C

3.5. PPR Pipe Results at 30°C

Specimen	Outside Diameter D (mm)	Wall Thickness t (mm)	Pressure P (Mpa)	Hoop Stress S(Mpa)	Time t(s)
1	32	4.4	5	15.6	4
2	32	4.4	4	12.5	5
3	32	4.4	5	15.6	5
4	32	4.4	5	15.6	6
5	32	4.4	5	15.6	6

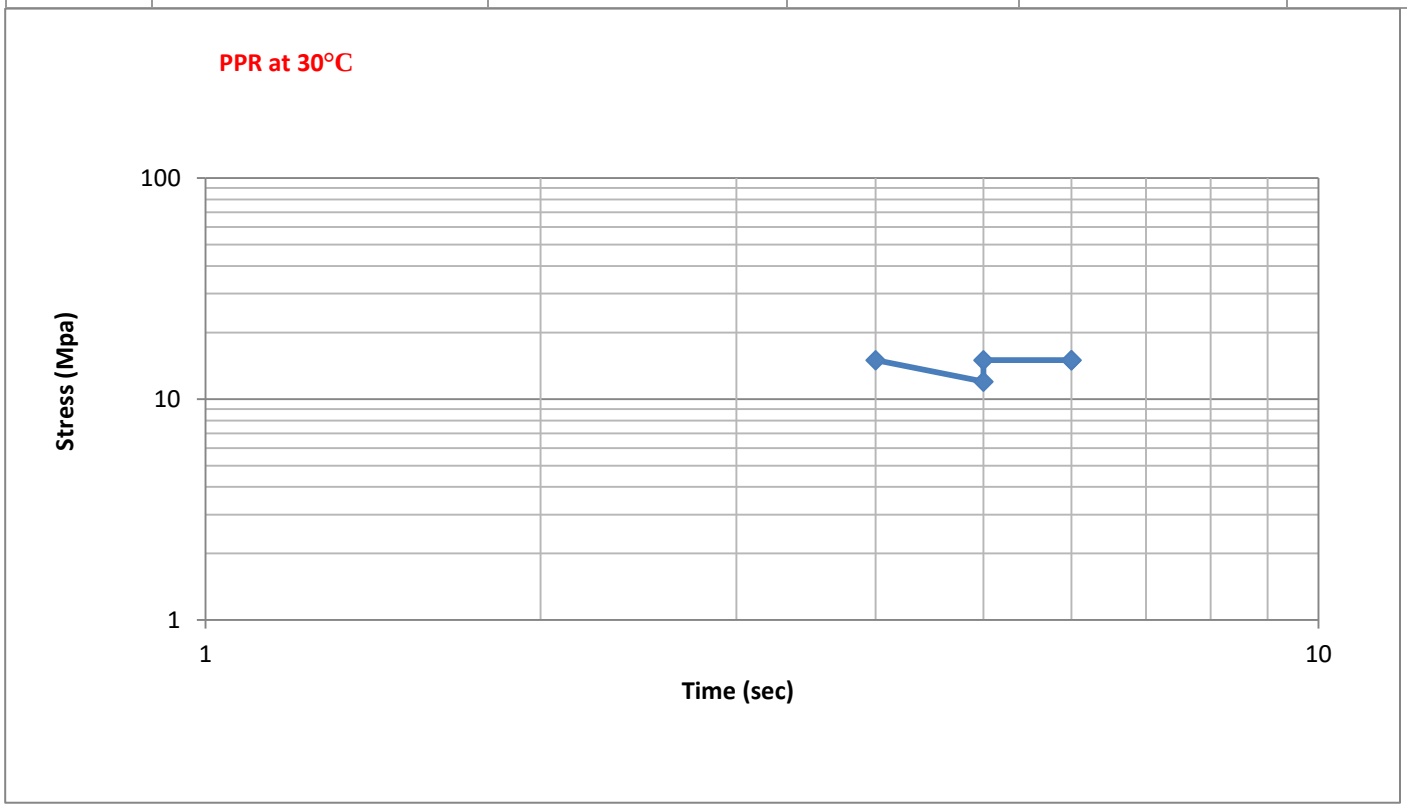

Figure 4: Stress-Rupture Curve for PPR Pipe at 30°C

3.6. PPR Pipe Results at 35°C

Specimen	Outside Diameter D (mm)	Wall Thickness t(mm)	Pressure P(Mpa)	Hoop Stress S(Mpa)	Time t(s)
1	32	4.4	7	21	5
2	32	4.4	7	21	6
3	32	4.4	6	18	6
4	32	4.4	7	21	7
5	32	4.4	6	18	10

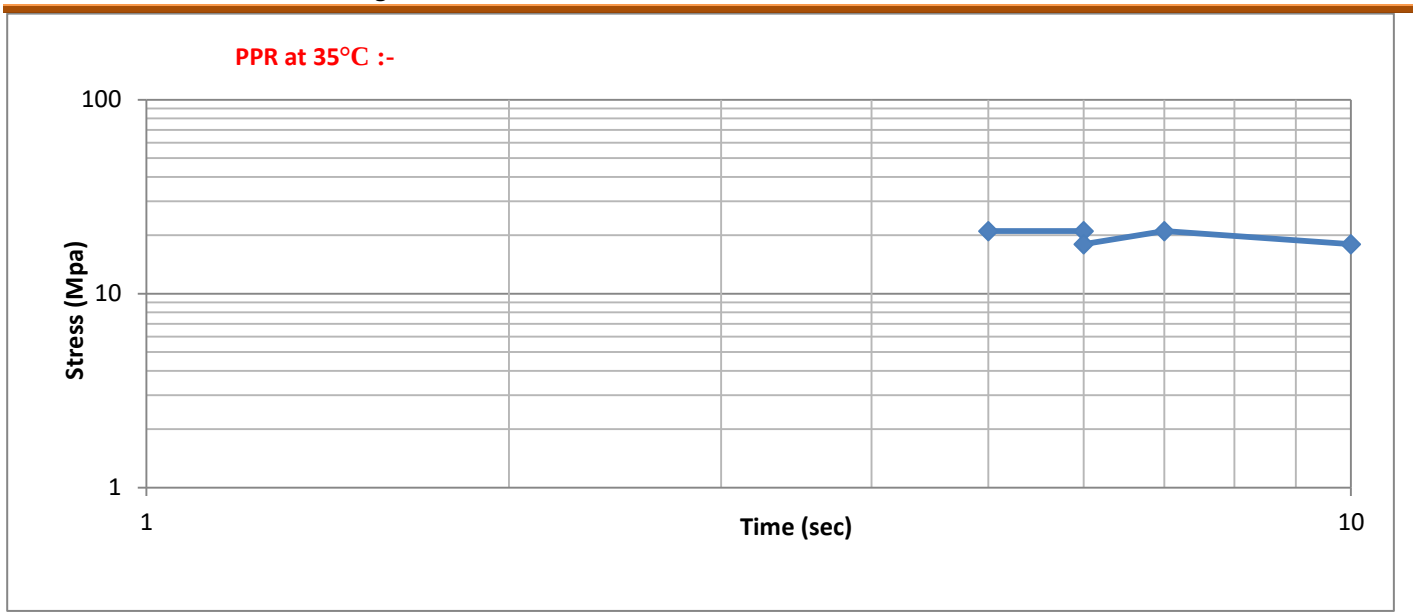

Figure 5: Stress-Rupture Curve for PPR Pipe at 35°C

3.7. PPR Pipe Results at 40°C

Specimen	Outside Diameter D (mm)	Wall Thickness t(mm)	Pressure P (Mpa)	Hoop Stress S (Mpa)	Time t(s)
1	32	4.4	4	12.5	4
2	32	4.4	4	12.5	4
3	32	4.4	5	15.6	5
4	32	4.4	3	9	5
5	32	4.4	4	12.5	5

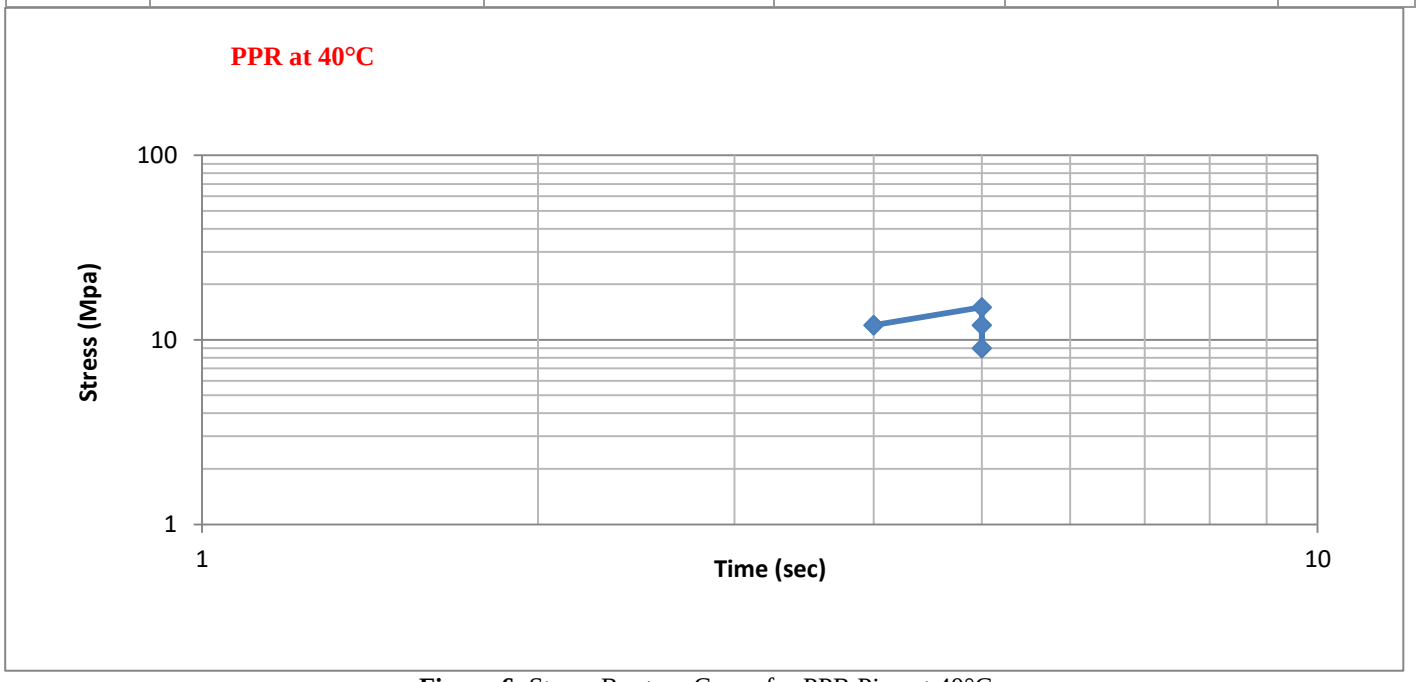

Figure 6: Stress-Rupture Curve for PPR Pipe at 40°C

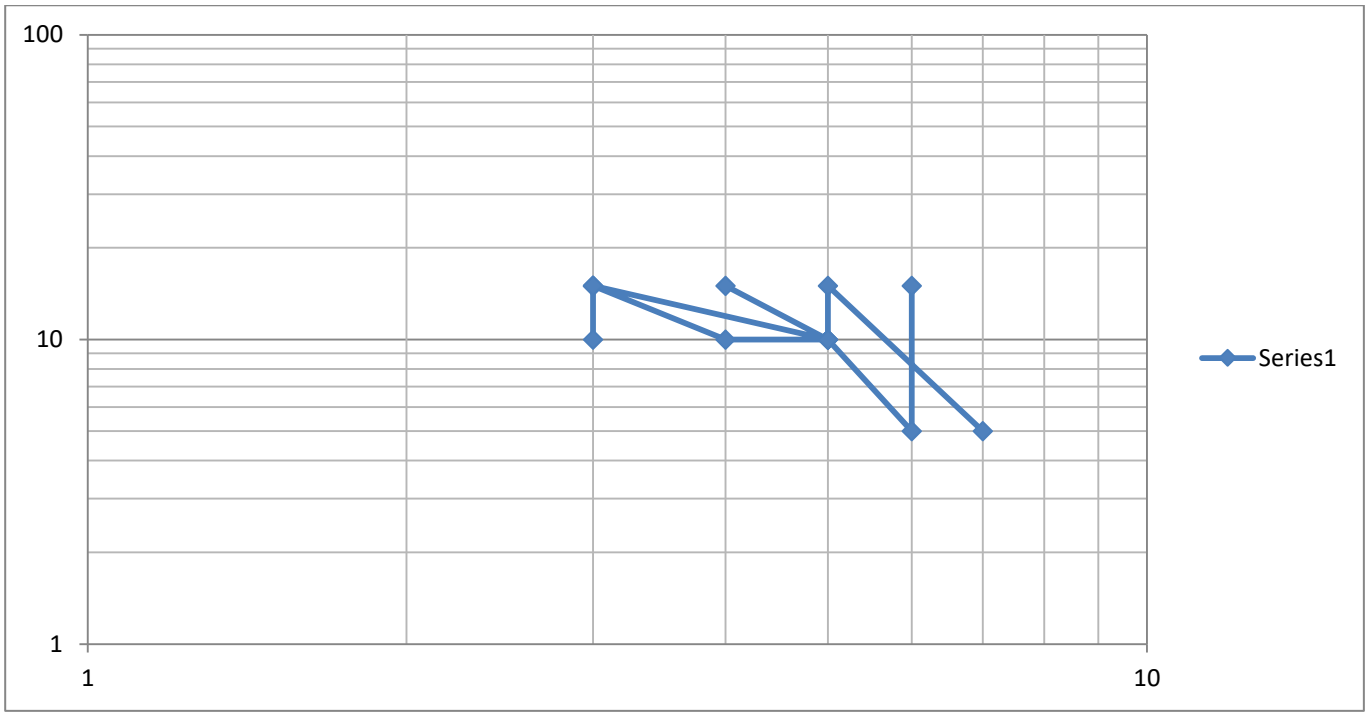

Figure 7: Combined Stress-Rupture Curves for PVC Pipe

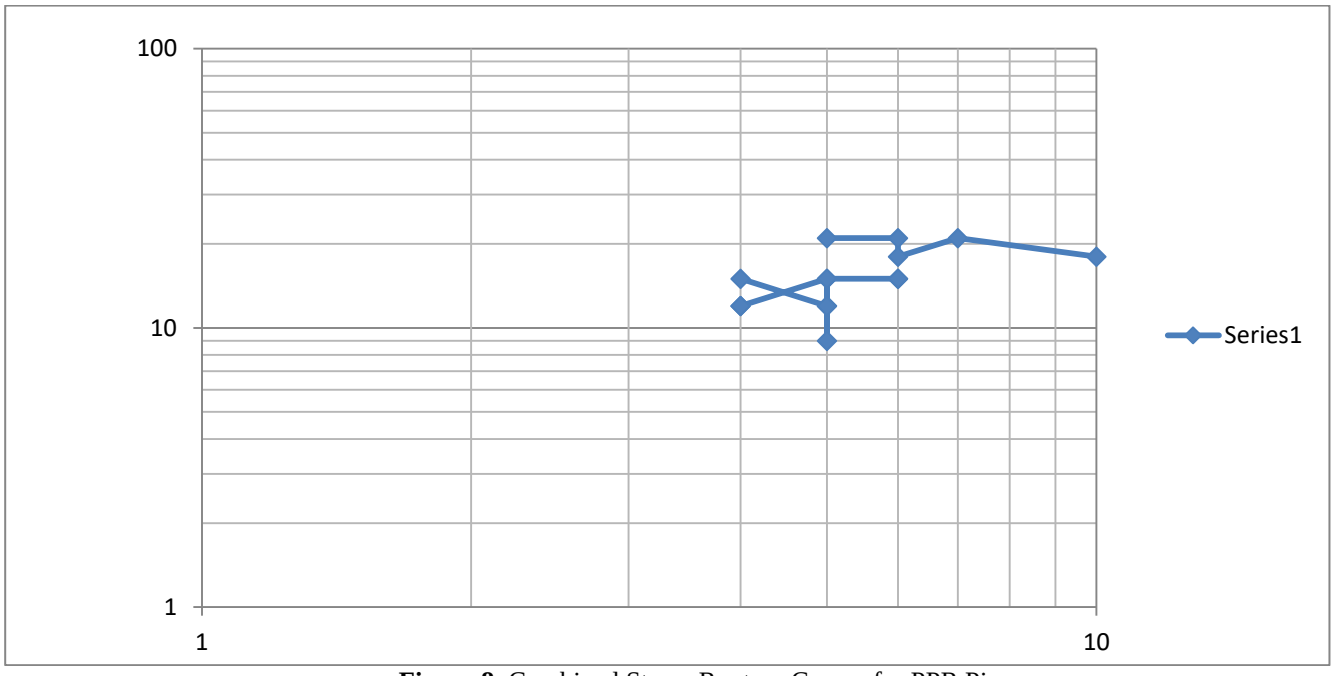

Figure 8: Combined Stress-Rupture Curves for PPR Pipe

4. DISCUSSION

The results from the stress rupture tests on PVC and PPR pipes at different temperatures (30°C, 35°C, and 40°C) show a clear relationship between the applied hoop stress and the time-to-failure. This behavior is consistent with the fundamental principle of stress rupture testing for thermoplastics, where a decrease in applied stress leads to a significant increase in the time-to-failure.

4.1. Comparison of PVC and PPR Pipe Performance

Comparing the performance of PVC and PPR pipes reveals that PPR pipes exhibit superior resistance to hydrostatic pressure. For instance, at 30°C, a PPR pipe required a pressure of up to 5 Mpa (hoop stress 15.6 Mpa) to rupture in a time ranging from 4 to 6

seconds, whereas a PVC pipe ruptured at 3 Mpa (hoop stress 15.56 Mpa) in a shorter time ranging from 3 to 6 seconds. This disparity becomes more pronounced at elevated temperatures (35°C and 40°C). While PPR pipes could withstand hoop stresses up to 21 Mpa at 35°C, PVC pipes did not exceed a hoop stress of 15.56 Mpa. This data suggests that PPR possesses better mechanical strength and higher creep resistance under thermal stress compared to PVC, supporting the conclusion that PPR pipes are the better choice for water supply applications, especially those involving elevated temperatures.

4.2. Effect of Temperature on Time-to-Failure

The analysis of the results clearly shows a negative impact of increasing temperature on the lifespan of both pipe types. For PVC pipes, at a constant hoop stress (approximately 15.56 Mpa), the average time-to-failure decreased from about 4 seconds at 30°C to about 3.6 seconds at 35°C, and further to 3 seconds at 40°C. Similarly, for PPR pipes, despite their higher resistance, a decrease in time-to-failure was also observed with increasing temperature. This aligns with the scientific concept that higher temperatures increase the mobility of polymer chains, accelerating creep and rupture mechanisms, and reducing the long-term hydrostatic strength of the material.

4.3. Significance of Stress-Rupture Curves

The graphical plots (as indicated in the original research) show the relationship between hoop stress (S) and time-to-failure (t) on a double logarithmic scale (Log S - Log t). These plots are expected to show straight or near-straight lines, where the slope of the line represents the material's degradation rate. It is observed that:

1. PPR Curves: PPR curves are expected to be higher and flatter (lower slope) than PVC curves, indicating greater resistance to long-term rupture.
2. Temperature Effect: The curves for both materials shift downwards and to the left as the temperature increases (from 30°C to 40°C), confirming the thermal acceleration of the failure process.

4.4. Impact of Recycled Materials

The results and conclusions confirm that the use of any percentage of recycled material negatively affects the pipe's lifespan. This is attributed to the degradation of the polymer's mechanical and thermal properties due to repeated processing cycles, leading to a reduction in stress rupture resistance and an increased likelihood of premature failure.

4.5. Discrepancy in Specifications

The recommendations point to a discrepancy between the specifications used in manufacturing (German) and those used in scientific testing (American), particularly concerning the dimensions of the end closures. This variation can lead to unrepresentative localized stresses near the end closures, potentially causing premature failure unrelated to the material's intrinsic properties. This justifies the recommendation to carefully examine failures and exclude values believed to be attributable to the end closure effect.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

- PPR pipes demonstrate superior performance and higher resistance to hydrostatic pressure compared to PVC pipes at all tested temperatures, making them the better choice for water supply applications.
- The presence of any percentage of recycled material in the pipe material negatively impacts the lifespan and stress rupture resistance of the pipe.
- The quality control sections in the majority of factories in Sudan use German specifications, while the devices available for scientific research work with the American standard, which differs from the German in the dimension of the test end closure.

5.2. Recommendations

- The difference in specifications used in the pipe design should be considered.
- It should be ensured that quality control equipment is provided with the same specifications as the specimens.
- The difference in results according to the percentage of recycled material in the pipe should be taken into account.

6. REFERENCES

[1] Farshad, M. (2005). Determination of the long-term hydrostatic strength of multilayer pipes. *Polymer Testing, 24*(5), 565–571.
[2] Litvinov, V. M., & Soliman, M. (2005). The effect of storage of poly(propylene) pipes under hydrostatic pressure and elevated temperatures on the morphology, molecular mobility and failure behaviour. *Polymer, 46*(11), 3843–3855.
[3] Krishnaswamy, R. K. (2005). Analysis of ductile and brittle failures from creep rupture testing of high-density polyethylene (HDPE) pipes. *Polymer, 46*(24), 10595–10603.
[4] Farshad, M. (2007). Long-term hydrostatic resistance of multilayer pipes. *Plastics, Rubber and Composites, 36*(3), 115–120.
[5] Boros, S. (2011). Long-term hydrostatic strength and design of thermoplastic piping compounds. *ASTM International.*
[6] Laiarinandrasana, L., Gaudichet, E., & Oberti, S. (2011). Effects of aging on the creep behaviour and residual lifetime assessment of polyvinyl chloride (PVC) pipes. *International Journal of Pressure Vessels and Piping, 88*(1), 1–8.
[7] Poduška, J., Kučera, J., Hutař, P., Ševčík, M., & Křivánek, J. (2014). Residual stress distribution in extruded polypropylene pipes. *Polymer Testing, 39*, 11–18.
[8] Rafiee, R., & Mazhari, B. (2016). Simulation of the long-term hydrostatic tests on glass fiber reinforced plastic pipes. *Composite Structures, 140*, 685–694.

[9] Geertz, J., et al. (2017). Residual life prediction of defected Polypropylene Random Copolymer (PPR) pipes. *Fracturae, 1*(1), 1–10.
[10] Ouardi, A., Mouhib, N., Wahid, A., & Elghorba, M. (2019). Comparative study of axial and circumferential defects severity on the failure of polypropylene (PPR) pipes. *Engineering Failure Analysis*, *104*, 104–114.
[11] Makris, K. F. (2020). A review on the durability of PVC sewer pipes: Research vs. practice. *Structure and Infrastructure Engineering*, *16*(1), 1–13.
[12] He, Y. (2021). Stress and failure analyses of thermoplastic composite pipes under combined pure torsion and thermomechanical loading from operational thermal cycles. *Composite Structures*, *262*, 113337.
[13] Ouardi, A. (2022). Effect of residual stresses on the fracture of polypropylene pipes. *Polymer Testing*, *105*, 107415.
[14] Espejo, E. (2023). Analysis of premature failure of a PVC water pipe. *Journal of Failure Analysis and Prevention, 23*(4), 1699–1707.
[15] Deveci, S., Khaleel, A., Eryigit, B., & AlHameli, F. (2024). Creep rupture of plastic pipes: Effect of eccentricity, residual stress, and circumferential orientation. *Polymer Testing, 132*, 108392.