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Evaluation of Burst Pressure on API X52 Pipes: Validation of Predictive Models via Full-Scale Experimental Data

Teddy Setiawan, Dedy Triawan Suprayogi, Hadi Wahyudi*
Mechanical Engineering Department, Universitas Sultan Ageng Tirtayasa,
Jl. Jend. Sudirman KM.3. Cilegon, Banten Indonesia

*E-mail: hadi.wahyudi@untirta.com

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Abstract

Ensuring the operational safety of steel pipelines depends heavily on understanding their failure points, or burst pressure. While various mathematical models are widely used in engineering practice, their accuracy for specific grades like API X52 often lacks robust field validation, as these models are essentially simplifications of complex real-world conditions. This study bridges this gap by evaluating the predictive accuracy of five major models-barlow, Von Mises, Zhu-Leis, API RP 1111 and DNV-OS-F101 against data obtained from a full-scale hydrostatic burst test. Using a pipe specimen with a 12 inch diameter and 11.13 mm wall thickness, the experimental result identified the actual burst pressure at 5,400 psi. comparative analysis revealed that the Barlow equation provided the highest accuracy with a relative error of only 4.12%, followed by the semi-empirical Zhu-Leis solution with a 6.97% deviation. Conversely, API RP 1111 method was found to be highly conservative by showing 17.24% deviation, which underscores its role as a safe design limit rather than a predictor of actual failure. These findings offer practitioners confidence that for thin-walled API X52 pipes with a diameter to thickness ratio of approximately 29, the Barlow model remains a practical and reliable reference for assessing pipeline integrity and estimating safe by operating limits.

Keywords: *API X52; burst pressure; full-scale experiment; pipeline integrity; theoretical prediction*

Abstrak

Memastikan keselamatan operasional pipa baja sangat bergantung pada pemahaman kita terhadap titik gagal atau burst pressure-nya. Meskipun berbagai model matematika secara luas digunakan dalam praktik teknik, akurasi model-model tersebut untuk kelas pipa API X52 seringkali kurang didukung oleh validasi lapangan yang kuat, karena model-model ini pada dasarnya merupakan penyederhanaan dari kondisi dunia nyata yang kompleks. Penelitian ini bertujuan untuk menjembatani kesenjangan tersebut dengan menguji akurasi lima model prediksi utama-Barlow, Von Mises, Zhu-Leis, API RP 1111 dan DNV-OS-F101 menggunakan data dari uji hydrostatic burst skala penuh. Dengan menggunakan spesimen pipa berdiameter 12 inci dan tebal 11,13 mm, ditemukan bahwa tekanan pecah aktual berada di angka 5.400 psi. Dari perbandingan yang dilakukan, persamaan Barlow terbukti paling unggul dengan tingkat akurasi tertinggi (error 4,12%), diikuti oleh solusi semi-empiris Zhu-Leis (error 6,97%). Di sisi lain, metode API RP 1111 menunjukkan sifat yang sangat konservatif dengan deviasi mencapai 17,24%, yang menegaskan fungsinya sebagai batas desain aman daripada titik kegagalan aktual. Temuan ini memberikan keyakinan bagi para praktisi bahwa untuk pipa berdinding tipis dengan rasio diameter-terhadap-tebal sekitar 29, model Barlow tetap menjadi referensi yang praktis dan andal dalam memprediksi batas aman operasional serta menilai integritas infrastruktur pipa.

Kata kunci: API X52; *burst pressure; eksperimen skala penuh;* integritas pipa; prediksi teoritis

1. Introduction

The ability of steel pipelines to withstand internal pressure is a critical component of structural safety in fluid transportation system. One of the most crucial elements is burst pressure, which is the pressure at which a pipe may catastrophically rupture. Despite its critical role, accurately predicting this value remains a significant engineering challenge due to the complex interaction between geometric tolerances and material non-linearity. Because analytical or mathematical formulas are easy to use as well as practical during design stages, they are frequently used in engineering practice to estimate burst pressure [1]. Thin-wall and thick-wall method, yield-based standards and theoretical models modified for a high strength steel pipe are common formulations [2]. In industrial applications, API X52 grade steel is widely utilized for its optimal balance between structural strength and weldability, making its reliability a priority for pipeline operators.

Although various theoretical equations are widely used to estimate burst pressure, these approaches are essentially simplifications of real world conditions [3], [4]. Variations in wall thickness, residual stress hardening behavior can cause prediction result to differ from actual burst performance [5]. While existing research has extensively explored burst behaviors in higher-grade steels like API X60 and X80 [6], the specific validation of predictive models using full-scale experimental data for API X52 remains relatively limited. This lack of grade specific validation is critical, as predictive equations calibrated for higher strength steels may not fully capture the plastic deformation characteristics of API X52 under actual operating conditions [3], [6]. On the other hand, full scale burst testing remains the most accurate way to determine a pipe maximum ability to withstand internal pressure [3]. However, this testing is rarely performed because it requires significant cost, specialized equipment and carries high operational risks. These conditions mean that experimental data especially for pipes with API X52 grade is still limited and has not been widely used to validate the various commonly used prediction methods.

Based on these requirements, this study presents a simple comparison between the results of burst test on 12 inch diameter API X52 pipe and several theoretical prediction approaches that are often used in design calculation. The main objective is to see how close the calculation results are to the actual behavior of the pipe when it fails, as well as to provide practical insights for engineers when assessing pipe integrity and estimating safe operating pressures. Specifically, this research seeks to identify which theoretical model-ranging from simple hoop stress to modern semi-empirical solutions-provides the highest accuracy and reliability for the specific material grade and geometry.

2. Materials and Methods

This section describes the characteristics of the API X52 pipe specimens, the experimental setup for the full-scale hydrostatic burst test, and the theoretical models used for validation. A systematic overview of the research process is illustrated in the flowchart in Figure 1.

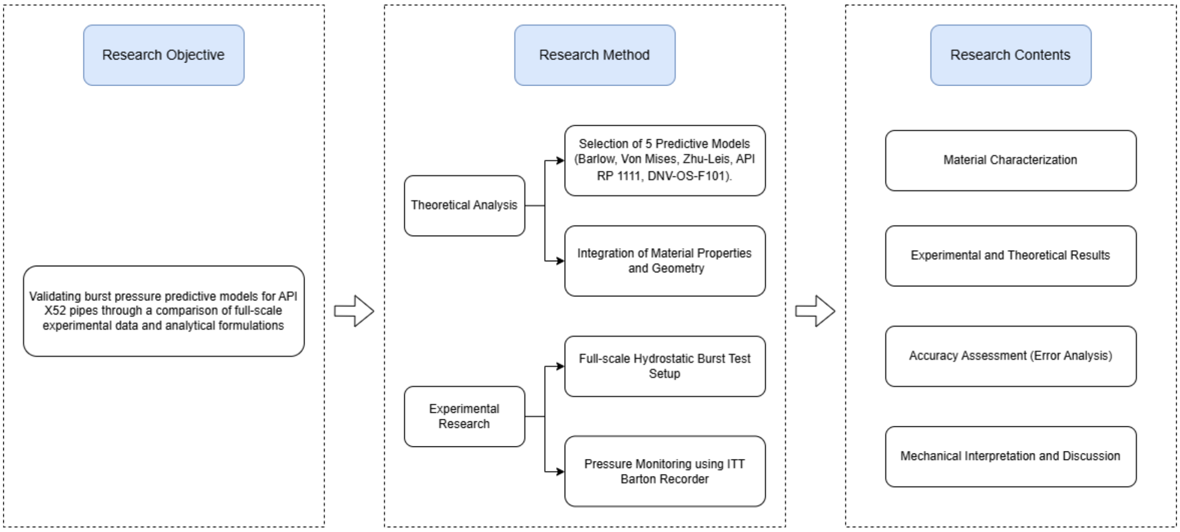

Figure 1. Systematic research flowchart of the methodology

2.1. Pipe Material and Properties

The specimen used in this study was a steel pipe API X52 as specified in API 5L with an outer diameter of 12 inches (323.9 mm) and an actual wall thickness of 11.13 mm [7]. The total length of the test specimen was 2050 mm to ensure that the burst behavior was not influenced by the end-cap constraints. The chemical composition of the material is presented in Table 1, confirming compliance with API 5L specifications [7]. The mechanical properties were derived from tensile tests conducted in accordance with the ASTM A370 standard as shown on Table 2 [8].

Table 1. Chemical Composition of API X52 Pipe (wt%)

Element	**C**	**Si**	**Mn**	**P**	**S**	**Cu**	**Ni**	**Cr**
Wt%	0.0632	0.2010	0.7990	0.0090	0.0048	0.0136	0.0090	0.0047

Element	**V**	**AI**	**N**	**Mo**	**Ti**	**Nb**	**B**	**Nb+V+Ti**
Wt%	0.0035	0.0346	0.0010	0.0011	0.0025	0.0349	0.0002	0.0409

Table 2. Mechanical Properties of the Specimen

Specimen Dimension	**Yield Strength (MPa)**	**Tensile Strength (MPa)**
API X52; OD : 323.9 mm, WT : 11.13 mm	446.62	519.42

2.2. Experimental Burst Test

The burst pressure test was performed using the hydrostatic method [9] to assess the ultimate strength of the pipe. Internal pressure was monitored and recorded using an ITT Barton Pressure Recorder with a measurement capacity of 0–15,000 psi. To ensure high data reliability, the instrument was calibrated according to the BS 1780-1985 procedure, demonstrating a measurement uncertainty (U_{95}%) of only ±0.09% with a coverage factor of k=2.00. The test involved closing both ends of the pipe with high-pressure end caps. One end was filled with water while the other was vented to ensure no air was trapped, as air pockets can cause unstable pressure readings. The internal pressure was increased gradually. After a preliminary leak check at medium pressure, the pressure was continuously increased until catastrophic failure occurred. The peak pressure recorded immediately before the drastic drop in the pressure curve was defined as the experimental burst pressure (P_{exp}) [10]**.**

2.3. Theoretical Prediction Methods

To calculate the burst pressure of pipes and compare it with the experiment results, various theoretical approaches are used, each representing a category of methods commonly used in pressurized pipe design [11]. The explicit equations for each method are described as follows:

Barlow Equation: This method is based on circumferential hoop stress for thin-walled conditions. The equation is expressed as equation 1 [1].

$$P = \frac{2t}{D}\sigma_{UTS} \tag{1}$$

Von Mises Criterion: This yield-based criterion considers the multi-axial stress state of the material. The burst pressure is predicted by equation 2 below [3].

$$P = \frac{4t}{\sqrt{3D}}\sigma_{UTS} \tag{2}$$

Zhu-Leis Solution: A modern semi-empirical model which, according to recent research, provides accurate predictions for defect-free pipes. The formulation used is as shown equation 3 [4].

$$P = \frac{1}{2}\left(1 + \frac{2}{\sqrt{3}}\right)\frac{2t}{D - t}\sigma_{UTS} \tag{3}$$

API RP 1111: A practical design formula widely used in industry which incorporates a theoretical safety factor. It is calculated as equation 4 [10].

$$P = 0.9\,(S + U)\frac{t}{D-t} \tag{4}$$

DNV-OS-F101: A standard method representing the theoretical upper bound of plasticity. The equation is defined equation 5 as [12].

$$P = 1.155 \frac{2t}{D-t} \sigma_{UTS} \tag{5}$$

Where P is the burst pressure, t is the wall thickness, D is the outside diameter, and σ_{UTS} (or U) represents the Ultimate Tensile Strength of the API X52 material.

2.4. Error Analysis

The accuracy of each method was evaluated using relative error calculation based on experimental result as shown in eq. 6. The method with the smallest error value was considered to be closest to the actual conditions [13].

$$E_r = \left| \frac{P_{theo-} P_{exp}}{P_{exp}} \right| \text{ x } 100\% \tag{6}$$

Where P_{theo} is the burst pressure predicted by the respective theoretical model.

3. Results and Discussion

This section evaluates the experimental burst test results against five predictive models, followed by a detailed mechanical interpretation of the failure behavior, material plasticity, and the influence of geometric ratios.

3.1. Burst Pressure Experimental Results

Testing of API X52 pipe with dimensions of 323.9 mm x 11.13 mm resulted in a burst pressure of 5400 psi. The failure was characterized by a longitudinal rupture in the pipe body, as shown in Figure 2. The fracture surface and the visible "bulging" around the failure zone indicate a classic ductile rupture [10]. This behavior is consistent with high-ductility steels like API X52, where significant plastic deformation occurs before the material reaches its ultimate tensile limit [6]. The failure occurred away from the end caps, confirming that the recorded pressure represents the true ultimate strength of the pipe material.

Figure 2. Burst pressure experiment results

3.2. Comparison of Theoretical and Experimental Results

The accuracy of the predictive models was assessed by comparing the analytical values with the experimental baseline of 5,400 psi. Table 3 summarizes the comparison, including the explicit equations to provide a clear technical basis for the deviation analysis.

Table 3. Comparison of the predictive equation of burst pressure theoretical with experimental value

Method	Predicted Equation	P_{burst} (psi)	Relative Error (%)
Barlow	$P = \frac{2t}{D} \sigma_{UTS}$	5,177	4.12
Von Mises	$P = \frac{4t}{\sqrt{3}D} \sigma_{UTS}$	5,978	10.71
Zhu-Leis	$P = \frac{1}{2}\left(1 + \frac{2}{\sqrt{3}}\right) \frac{2t}{D-t} \sigma_{UTS}$	5,776	6.97
API RP 1111	$\mathrm{P} = 0.9\,(\mathrm{S} + \mathrm{U}) \frac{t}{D-t}$	4,469	17.24
DNV-OS-F101	$\mathrm{P} = 1.155 \frac{2t}{D-t} \sigma_{UTS}$	6,192	14.68

3.3. Mechanical Interpretation and Discussion

The high accuracy of the Barlow equation (4.12% error) is particularly noteworthy. This accuracy is primarily attributed to the pipe's diameter-to-thickness (D/t) ratio of approximately 29.1. In pipelines mechanics, a D/t ratio greater than 20 classifies the structure as a thin-walled cylinder, where assumption of uniform hoop stress-the core of the Barlow model- remains highly valid [14]. Furthermore, the material's ductility played a critical role in the failure progression. The Y/T ratio of the specimen was 0.86 (446.62 MPa / 519.42 MPa), which indicates a significant capacity for strain hardening. This allows the pipe to sustain increasing internal pressure through plastic expansion before localized necking and eventual rupture occur [15]. The Zhu-Leis model, which accounts for this multi-axial plastic behavior also yielded a relatively low error of 6.97%, serving as an average prediction while Von Mises as an upper bound prediction [16]. While higher grade steels such as API X60 and API X80 typically sustain higher burst pressure due to their superior material strength, the result for this API X52 specimen indicate that for thin-walled geometries (D/t = 29.1), failure behavior remains highly predictable and consistent with standard analytical models [17]. In contrast, the API RP 1111 method provided the most conservative estimate (17.24% error). This significant underestimation is expected as the formula is designed for limit state safety assessment, incorporating a 0.9 safety factor to ensure operational integrity rather than predicting the exact point of catastrophic failure [10]. The experimental result of 5,400 psi falls within a predictable analytical range bounded by the conservative Barlow estimation and the optimized Zhu-Leis criterion validating the reliability of the test data for API X52 grade pipes.

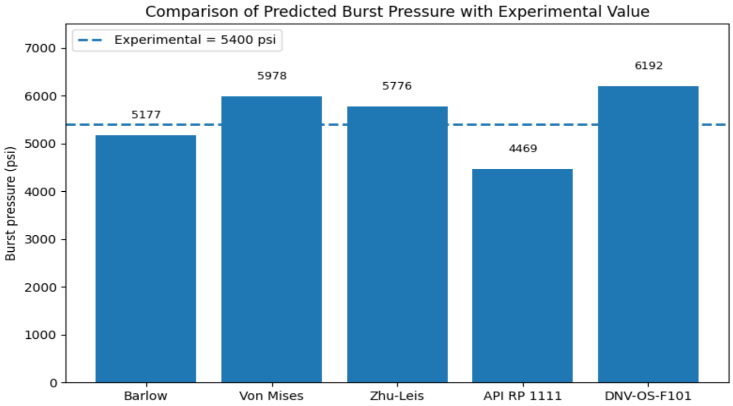

Figure 3. Comparison of predicted burst pressure with experimental value

4. Conclusion

The burst pressure on a 12-inch diameter API X52 pipe was 5400 psi and the pipe body was where it failed. The failure pattern showed ductile failure, which is when significant plastic deformation occurs before rupture [10]. This is consistent with the characteristics of API X52 steel which generally experiences ductile rupture under internal loading [6]. From the comparative analysis, the Barlow equation and the Zhu-Leis semi-empirical model provided the most accurate predictions, with relative errors below 7%. The high accuracy of the Barlow model confirms that for thin-walled API X52 pipes with a D/t ratio of approximately 29, the assumption of uniform hoop stress remains a valid and practical tool for engineers. In contrast, industrial standards such as API RP 1111 yielded significantly conservative results, reflecting their primary function as safe design limits rather than failure predictors. This philosophy aligns with Fitness-for-Service methodologies where allowable limits are separated from actual collapse pressure [18]. The primary scientific contribution of this research is the empirical validation that simple circumferential stress-based equations can match the accuracy of complex plastic behavior models for defect-free API X52 pipes under specific geometric conditions. However, this study is limited by the use of a single, defect-free specimen, which may not fully represent the variability of aged or corroded industrial pipelines. Future research should focus on validating these models for pipes with varying D/t ratios and investigating the influence of localized defects, such as corrosion pits or cracks [18].

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