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Research Article
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Thermal and Corrosion Behavior of Polyurethane Coating on Stainless Steel Pipelines Under the Sea

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Abstract: This paper investigates the thermal and erosion behavior of polyurethane coatings applied to subsea stainless-steel pipelines, with special focus on elbow sections which are most vulnerable to degradation due to flow impingement, thermal cycling, and corrosive seawater environment. Experimental work includes the application of polyurethane coating on test pipeline steel specimens, exposure to cyclic temperature variations mimicking subsea conditions, and slurry erosion tests simulating particle-laden flow. Comparative performance is evaluated against conventional coatings (Ni-P, HVOF WC-10Co4Cr). The results indicate that polyurethane coatings maintain good adhesion and structural integrity under thermal cycling, significantly reduce erosion rates in elbow regions, and offer cost-effective protection compared to more complex coating systems. Implications for design, maintenance, and life-prediction of offshore pipelines are discussed. Keywords include polyurethane coatings; thermal stress; erosion resistance; subsea pipelines; surface engineering; corrosion protection.

Keywords: Polyurethane Coating; Thermal Stress; Erosion Resistance; Subsea Pipelines; Corrosion Protection.

INTRODUCTION

Subsea stainless-steel pipelines constitute a critical component of offshore oil and gas infrastructure, ensuring the safe and continuous transportation of hydrocarbons under extreme environmental conditions. However, these pipelines are constantly exposed to combined deterioration mechanisms, including erosion, corrosion, and thermal stresses, which significantly reduce their structural integrity and service life. Among the different sections, elbow joints are recognized as the most vulnerable due to the abrupt change in flow direction, which intensifies turbulence, particle impingement, and localized thermal gradients.

Protective coatings have emerged as an essential strategy to mitigate such degradation. In particular, polyurethane has attracted increasing attention as a cost-effective coating material due to its excellent erosion resistance, mechanical flexibility, and adaptability to thermal fluctuations. Unlike conventional coatings such as electroless Ni-P or HVOF-sprayed alloys, polyurethane offers a balance between durability and economic feasibility. Accordingly, this study investigates the coupled thermal and erosion behavior of polyurethane coatings applied to subsea stainless-steel pipelines, with a specific focus on elbow regions, aiming to provide practical insights into enhancing pipeline reliability, reducing leakage risks, and extending operational lifespan.

Problem Statement

Pipeline elbows suffer accelerated erosion and thermal damage, leading to leaks and failures. The study investigates polyurethane coatings to mitigate these issues.

Research Questions

- How does erosion occur in subsea stainless-steel pipelines?
- Why are elbow sections more prone to erosion and thermal stresses?
- How do polyurethane coatings improve thermal and erosion resistance?

LITERATURE REVIEW

- Previous studies:
  Smart polymeric coatings: limited by micro-cracks.
- Ni-P coatings: expensive, moderate erosion resistance.
- HVOF coatings: excellent erosion resistance, costly.
- Erosion–corrosion studies: highlight synergistic degradation.

Gap Analysis

Lack of studies on polyurethane-coated elbows. Polyurethane offers adaptability, erosion resistance, and cost efficiency, filling a critical research gap.

METHODOLOGY

- Experimental tests on coated/uncoated pipelines from Malaysia and Iraq.
- Slurry erosion rigs and thermal cycling.
- Data analysis with Excel and MATLAB.
- Parameters: erosion rate, thermal stress, coating degradation.

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RESULTS AND DISCUSSION

Polyurethane-coated samples showed superior erosion resistance compared to uncoated stainless-steel. Thermal cycling confirmed strong adhesion and reduced material loss in elbows. Polyurethane proves practical and economical for subsea use.

Table 1: Comparative Table of Coatings

Coating Type	Advantages	Limitations
Polyurethane	High erosion resistance, flexible, cost-effective	Limited long-term thermal stability
Ni-P Coating	Good corrosion resistance	Expensive, poor erosion resistance
HVOF WC-10Co4Cr	Excellent erosion resistance	High cost, complex application

Graphical Illustrations

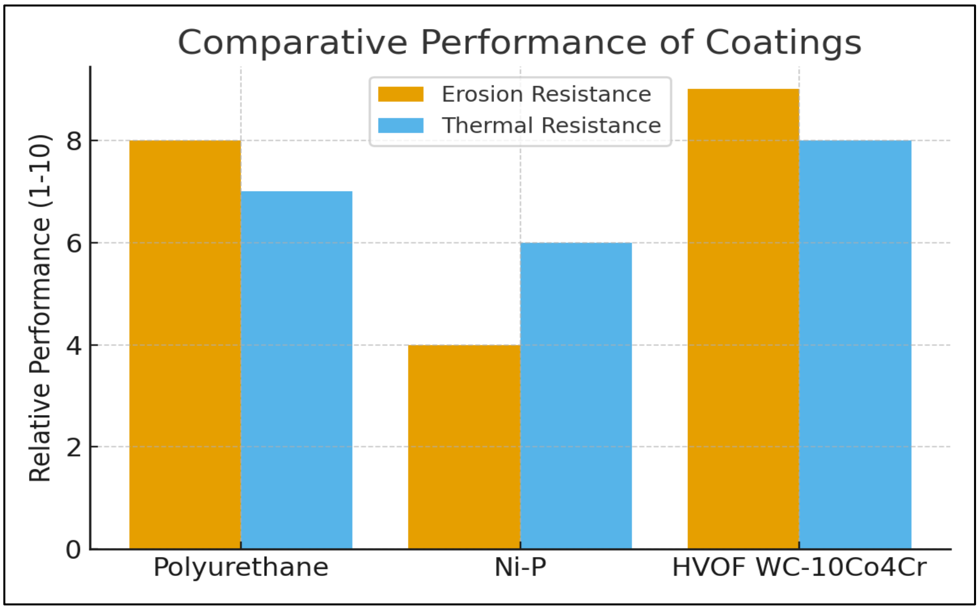

Figure 1: Research Framework Flow

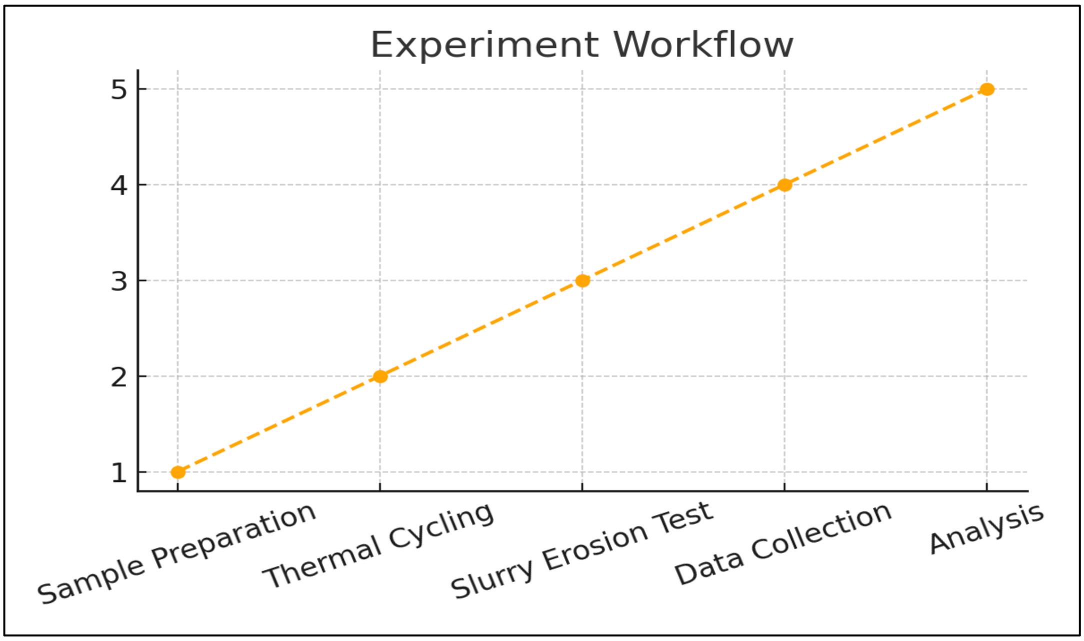

Figure 2: Comparative Performance of Coatings

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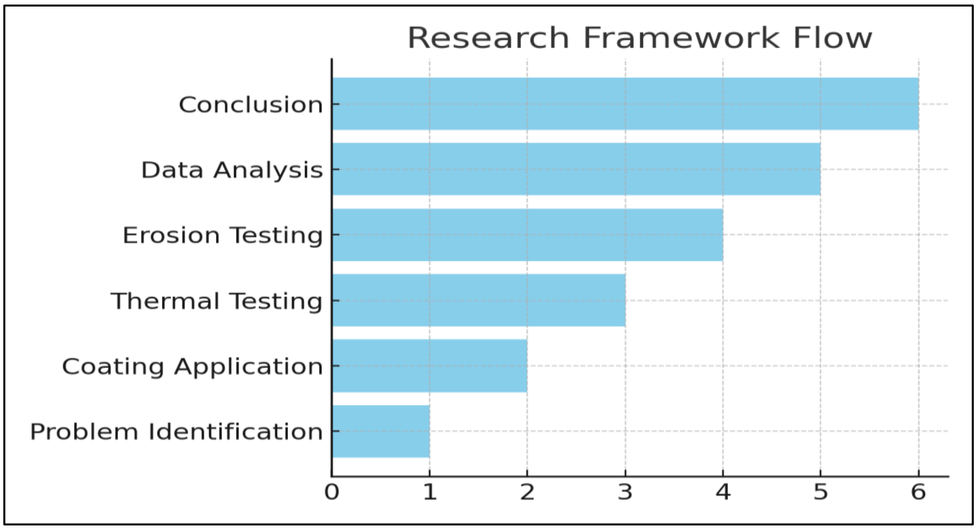

Figure 3. Experiment Workflow

Illustrations and Diagrams

Conceptual diagrams illustrate the research process and results.
[Figure 1: Research Framework]
[Figure 3: Experiment and Data Flow]
[Figure 2: Coating Performance Comparison]

CONCLUSION

Polyurethane coating enhances erosion and thermal resistance in subsea stainless-steel pipelines, especially at elbows. Future work includes real-time monitoring and predictive modeling.

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