



GUJARAT TECHNOLOGICAL UNIVERSITY

(Established by Government of Gujarat under Gujarat Act No. : 20 of 2007)

ગુજરાત ટેકનોલોજીકલ યુનિવર્સિટી

(ગુજરાત સરકારના ગુજરાત અધિનિયમ ક્રમાંક : ૨૦/૨૦૦૭ દ્વારા સ્થાપિત)

Accredited with A++ Grade by NAAC

Abstract of the Thesis



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Faculty: Engineering

Discipline/Branch: Mechanical Engineering

Title of the Thesis: Experimental and Numerical Investigation of Fatigue Failure of Miter Bend Subjected to Various Loading Conditions

Abstract

Content of the abstract: Miter bends offer economical and flexible flow-direction changes in industrial piping, but their angular geometry and welded joints create severe stress concentrations. This research investigates the fatigue behavior of fabricated 90° miter bends under combined dead-weight and resonant-vibration loading through an integrated experimental, finite element, analytical and Machine Learning approach. Twenty-seven specimens covering three outside diameters, three wall thicknesses and one-, two- and three-weld configurations were fabricated, inspected and tested. Modal and harmonic analyses identified resonant frequencies and fatigue hot spots, while strain-gauge measurements established experimental stress amplitudes and fatigue lives. The study demonstrates that weld layout and wall thickness govern fatigue resistance, validates the numerical model against experiments and develops a rapid data-driven prediction framework.

Research Problem: Existing design approaches mainly address pressure or static loading and provide limited guidance for welded miter bends operating near resonance. The combined effect of dead weight, vibration, wall thickness, pipe diameter and weld configuration on crack initiation and



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fatigue life had not been systematically quantified or experimentally validated.

Methodology followed for Research: A 3-factor, 3-level full-factorial design produced 27 combinations: OD 141.3, 219.1 and 323.8 mm; thickness 0.511, 0.9 and 1.2 mm; and 1W, 2W and 3W configurations. SolidWorks-based patterns were fabricated from GI sheets, verified by CMM and screened by MPT. ANSYS modal and harmonic analyses determined natural frequencies, stresses and gauge locations. Each specimen was tested in a fixed-free condition under a 40 kg dead weight and non-contact electromagnetic excitation at resonance. Fatigue life was obtained from crack-initiation time multiplied by excitation frequency. Experimental results were compared with FEA and Basquin predictions, followed by MLR, Decision Tree and Random Forest regression modelling.

Outcome of the Research:

- Experimental fatigue life ranged from 4.32×10^5 to 5.33×10^6 cycles at stress amplitudes of 57.4–351.1 MPa. The 3W specimens consistently outperformed the corresponding 2W and 1W specimens.
- Weld configuration and wall thickness were the dominant factors, contributing 46.6% and 39.4%, respectively, of the variation in log fatigue life. Pipe diameter had a comparatively weak influence (3.7%).
- Increasing thickness from 0.511 mm to 1.2 mm increased mean fatigue life from 1.02×10^6 to 3.04×10^6 cycles. Changing from 1W to 3W increased geometric-mean fatigue life by approximately three times.
- Experimental and FEA fatigue lives showed strong agreement ($R^2 = 0.96$; MAPE = 3.65%). Basquin predictions were acceptable mainly at intermediate stresses and were unreliable at the stress-range extremes for welded thin-wall joints.
- Random Forest Regression performed best among the evaluated ML models and provided rapid fatigue-life screening. More conservative validation indicated an expected R^2 score of approximately 0.7–0.8 for unseen data.

Application: The findings are applicable to process-gas, cooling-water, compressed-air, hydraulic, lubrication and fume-extraction piping in integrated steel plants and other vibration-prone industries.



They support safer weld-layout selection, wall-thickness optimization, identification of likely crack locations, resonance-aware inspection planning, preliminary fatigue-life screening and condition-based maintenance of fabricated piping systems.

This PhD Thesis will help in improving the fatigue-resistant design and reliability assessment of welded miter bends by combining validated experiments, FEA and data-driven prediction. The work helps engineers prioritize multi-weld configurations and adequate wall thickness, locate critical inspection zones, avoid resonance-related failures, reduce repeated simulations during preliminary design and develop practical design charts or digital tools for predictive maintenance.

List of Publication(s):

- 1) N. B. Rathod and D. C. Patel, "A Review Article on Fatigue Life Estimation of Miter Bend," Journal of Mines, Metals and Fuels, 2024. <https://doi.org/10.18311/jmmf/2023/43086>
- 2) N. B. Rathod and D. C. Patel, "Development of Machine Learning Regression Models to Assess von Mises Stress of Miter Bend," Journal of the Institution of Engineers (India): Series C, 2025. <https://doi.org/10.1007/s40032-025-01181-0>
- 3) N. B. Rathod and D. C. Patel, "Fatigue Life Assessment of 90° Miter Bends under Resonant Vibration Using Strain Gauge Measurements and Numerical Analysis," International Journal of Engineering Research & Technology, 2026. <https://doi.org/10.5281/zenodo.19287651>