

Tetra-Parametric Assembly Method Coupled with Three-Network Constitutive Model for Improved Design of HDPE–Steel Flange Assemblies

Imad Barsoum¹, Sherif Ezzeldin²

¹ Khalifa University, United Arab Emirates. imad.barsoum@ku.ac.ae

² Khalifa University, United Arab Emirates. 100064449@ku.ac.ae

Paper ID: 17

[Symposium SI: Mechanical behavior of polymers and biopolymers: theory, simulations and testing](#)

Abstract

The performance of bolted flange connections is critically influenced by the interaction between bolt tightening procedures and the mechanical response of the joint materials. This challenge becomes particularly complex in hybrid assemblies of high-density polyethylene (HDPE) pipes and steel flanges due to the large mismatch in stiffness and the viscoelastic-plastic nature of HDPE. Conventional tightening procedures often fail to ensure uniform bolt preload and contact pressure, thereby compromising sealing integrity and long-term reliability. To address these issues, this work presents a computational framework that integrates the Tetra-Parametric Assembly Method (TAM) with a calibrated Three-Network (TN) nonlinear constitutive model for HDPE. TAM offers a streamlined yet accurate approach to characterize bolt–bolt elastic interactions, reducing the complexity of conventional elastic interaction methods by capturing preload redistribution using only four interaction parameters. Its efficiency allows accurate prediction of bolt preload requirements in single-pass tightening sequences, enabling improved assembly strategies with reduced computational and experimental effort. The TN constitutive model complements this by accurately representing the time-, temperature-, and load-dependent behavior of HDPE, including relaxation and creep phenomena, based on extensive short- and long-term experimental calibration. The integrated TAM–TN framework was implemented in finite element simulations of HDPE–steel flange

assemblies under both isothermal and thermally transient service conditions. Results demonstrate that TAM significantly improves the uniformity of contact pressure compared to conventional torque-controlled methods, thereby enhancing sealing performance. Meanwhile, the TN model reveals strong temperature sensitivity: elevated service temperatures accelerate stress relaxation and reduce contact pressure, leading to earlier onset of leakage unless corrective re-torquing is performed. Simulations of year-long thermal cycling further highlight that multiple re-torquing interventions, guided by TAM predictions, are essential to sustain sealing integrity under realistic outdoor service conditions. This study provides both methodological and practical contributions. Methodologically, it advances bolt-tightening analysis through the combination of the efficiency of the TAM approach and the accuracy of the TN constitutive model for HDPE. Practically, it offers engineers a predictive tool to design, assemble, and maintain HDPE–steel flange joints with improved reliability in temperature-sensitive applications such as petrochemical, energy, and water infrastructure systems. By explicitly accounting for elastic interactions and viscoelastic relaxation, the TAM–TN framework lays the foundation for establishing optimized tightening protocols and maintenance schedules, reducing leakage risk and extending service life of polymer–metal flange assemblies.

Keywords:

Thermoplastics Constitutive modeling Finite element analysis Tetra-parametric assembly method Three-network constitutive model Bolted flange connection