

How Microscopic Deformations Extend the Lifespan of Industrial Bolts

Conventional design standards predict that the large bolts used in gasketed plate heat exchangers should fail much earlier than they do in practice. This thesis shows how microscopic changes in the material during assembly dramatically increase their fatigue life.

Gasketed plate heat exchangers are massive, critical machines used in everything from food processing to global energy production. Holding these heavily pressurized systems together is a set of large, high-strength tightening bolts. These bolts endure extreme forces: during assembly, they are tightened so hard that the metal at the root of the threads actually deforms. Then, during everyday operation, they are subjected to thousands of tiny, high-frequency pressure fluctuations.

If you calculate the lifespan of these bolts using the standard European design codes, the math delivers a grim verdict: the bolts should fail prematurely. Yet, looking at decades of real-world industrial data, they simply don't. They survive for years without issue. So, why is the rulebook wrong?

This thesis solves that mystery by abandoning the macroscopic, traditional rules and looking at the microscopic physics inside the bolt threads.

The standard design codes assume that metal always behaves perfectly elastically, like a simple rubber band. But using advanced computer simulations (Finite Element Analysis), this research reveals a completely different reality. Because the tightening force during assembly is so extreme, the very bottom of the bolt's thread permanently yields.

The magic happens when the heat exchanger is unloaded for maintenance. The massive, unyielded core of the bolt snaps back to its original shape, acting like a "giant spring." As it snaps back, it forcefully crushes that tiny, yielded thread root, locking it into a state of deep, permanent compression.

This residual compression acts as an invisible, protective shield. It tightly locks the thread in place so that the tiny, everyday pressure fluctuations of the machine barely affect the metal at all—a phenomenon known as "elastic shakedown."

By proving that this extreme initial tightening actually protects the fastener rather than destroying it, this research shows that the bolts can withstand over 270,000 cycles, rather than the meager 2,000 predicted by the code. Ultimately, this allows engineers to safely rethink how they design these massive machines, unlocking hidden structural capacity, reducing material waste, and proving that sometimes, a component's greatest strength is hidden in its microscopic deformations.